STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF FACILITIES CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

EFFECTS ON A VEHICLE IMPACTING A CONCRETE SAFETY SHAPE BARRIER AT A LOW SPEED AND A LARGE ANGLE

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16. ABSTRACT

This report presents the results of one vehicle crash test into a safety shape (New Jersey) concrete barrier with a lightweight car having an unusually high impact angle and an unusually low impact speed. The barrier consisted of four 20-ft segments with pinned end connections similar in design to the Caltrans Temporary Railing (Type K) and was anchored to prevent lateral deflection during impact. The test vehicle weighed 1860 lbs and had an impact speed and angle of 27.4 mph and 52° respectively. The objective of the test was to evaluate any adverse effects on the vehicle and 5th percentile female dummy driver due to the unusual impact conditions. Immediately after impact the car climbed partially up the face of the barrier and rolled over on its right side where it stayed at an angle of 69° with the barrier and within two feet of the barrier.

Using evaluation criteria for occupant risk and vehicle trajectory, as contained in NCHRP Report 230, it was concluded that the chance of severe or fatal injuries to a vehicle driver or passenger would be very high when impacting a concrete barrier under the conditions of this test.

17. KEY WORDS Collision, median barrier, impact test, crash worthiness, deceleration, female driver, small car.		18. DISTRIBUTION STATEMENT No Restrictions.	
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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic years (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

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Jim Keesling, crash test coordination and preparation, and test film handling. Suema Hawatky, crash test preparation, data reduction, and test report. Eldon Wilson, test vehicle and crash test preparation. Doran Glauz, report review, Robert Ratcliff, preparation of test vehicle. William Ng and Delmar Gans, electronic instrumentation and data reduction. Leoncio Lopez, drafting for final report. Marti Garcia-Corralejo, word processing of final report.

Thanks are due also to the California Highway Patrol (CHP) Academy for loaning us the concrete barrier segments for use as a test barrier, and to MCR Inc., for loaning us the female dummy used for the test.

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1. INTRODUCTION

1.1 Background

For almost 30 years Caltrans has been placing median barriers on freeways where high traffic volumes, median widths and/or other considerations may warrant them. The Caltrans Traffic Manual describes these warrants in detail(1)*.

Median barriers prevent generally high energy headon collisions which sometimes occur when out of control vehicles cross the median into the opposing lanes.

Before Caltrans adopts new median barrier designs for use, they crash test prototype barriers to check them for crashworthiness. National Cooperative Highway Research (NCHRP) Report No. 230, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances"(2) contains national standards used by Caltrans for such testing. This report calls for two tests on any new median barrier design. The first, a strength test of the barrier, uses a 4500 lb car with an impact speed/angle of 60 mph/25°. The second, an occupant risk test, uses an 1800 lb car with an impact speed/angle of 60 mph/15°. The first test specifies impact conditions designed to be more severe than most passenger car impacts of the barrier. The second test reflects a more typical set of impact conditions. Neither test represents extreme impact angles which occasionally occur. Barriers are typical of all engineered structures in that they are never designed for the most extreme loading conditions conceivable. Median barriers have always been subjected to the heavy car "proof" test. Only in recent years have the lightweight car impacts been added in recognition of the increasing lightweight car population.

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* Numbers in parentheses and underlined refer to a reference list at the end of this report.

In tort liability cases involving State highways, probable impact conditions often fall in the small band of accidents which are more extreme than crash test conditions. Predicting just how a vehicle will behave under those unusual conditions may prove difficult. One such case came to light recently. This case involved an accident where no median barrier was present and an out-of-control Honda Civic traveled across the median and struck a wall on the far side of the opposing lanes. If a median barrier had been in place, the Honda would have hit it at an impact speed and angle of approximately 27 mph/52°.

Most crash tests on median barriers have been performed using the guidelines of NCHRP 230 or similar tests based on earlier guidelines. The researchers were familiar with the technical literature dealing with median barrier crash tests, and knew there were no tests with impact conditions of 27 mph/52°. These conditions differ from normal crash test conditions; hence, it was difficult to predict from prior crash tests how the Honda and a median barrier would interact.
The researchers assumed that had a median barrier been in place before the accident, it would have been a safety shape concrete barrier.

1.2 Objectives/Scope

The objective of this study was to conduct a crash test of a safety shape concrete barrier with a lightweight car impacting at an unusually low speed and large angle. Specifically, an 1860 lb Honda Civic was to impact the barrier at a speed of 27 mph and an angle of 52°. Test results were compared with the Safety Evaluation Guidelines in NCHRP Report 230. Adverse effects on the car and dummy driver due to the impact were to be evaluated.

2. CONCLUSIONS

The following conclusions are based on the results of an 1860 lb vehicle/27.4 mph/52° impact test, Test 431, into a safety shape concrete barrier.

- The test barrier did not move laterally or rotate about its longitudinal axis during impact and suffered no structural damage.

- Rollover of the vehicle immediately after impact was caused primarily by excessive rolling and pitching motions induced by the barrier, but was not related to the structural strength and stability of the barrier. The uncontrolled rollover trajectory of the test vehicle occurred because of the particular impact conditions of a light weight car, large angle, and low speed.

- The theoretical values of dummy head relative velocity (longitudinal occupant impact velocity) when striking the steering wheel, and the left front door post after two feet of travel was 32.9 feet per second, higher than the recommended acceptance value of 30 feet per second for longitudinal barriers.

- The test results from this impact were more severe than the limiting test results specified for highway safety devices in NCHRP Report 230(2). The chance of severe injuries or death to passengers in an accident similar to this test would be high, particularly if no seat restraints were used.

3. TECHNICAL DISCUSSION

3.1 Test Conditions

3.1.1 Test Facilities

The crash test was conducted at the Caltrans Dynamic Test Facility in Bryte, California, near Sacramento. The test took place on a flat asphalt concrete surface.

3.1.2 Test Barrier

A former test barrier similar to Caltrans Temporary Railing Type K was used for the test. It was 80 feet long and composed of four 20 foot sections. The barrier had a safety shape (New Jersey) profile identical to the profile of the Caltrans Type 50 Concrete Barrier. It was placed on top of an asphaltic concrete surface. It was bolted to a footing at one point and backed up with two barrier segments, set perpendicular to the test barrier near impact point, to minimize barrier movement. The test barrier is shown in Figures 1 and 2.

3.1.3 Test Vehicle

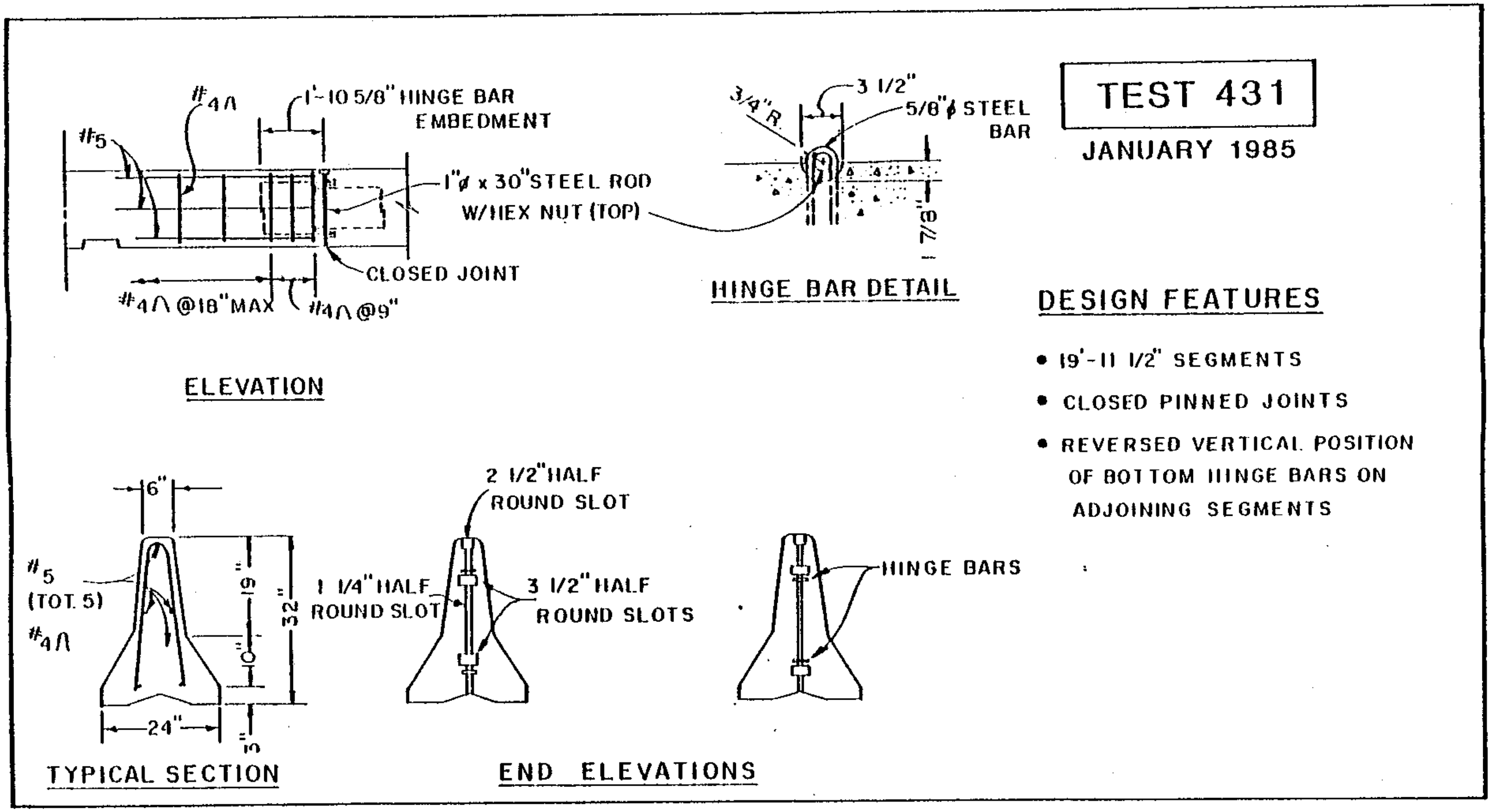
The test vehicle was a 1975 Honda Civic weighing 1860 lb, not including the dummy, Figure 3. It was in good condition, free of body damage and without missing structural parts. All equipment on the vehicle was standard. The engine was front mounted. No ballast was used. Vehicle dimensions are shown in Figure A1 in Appendix A.

The vehicle was self-propelled. Guidance was achieved with an anchored cable and there were no constraints placed on the steering wheel. A short distance before the point of impact the vehicle was released from the guidance cable and the ignition was turned off. A detailed description of the vehicle equipment and guidance system is contained in Appendix A.

3.1.4 Test Dummy

An anthropometic/anthropomorphic dummy, was placed in the driver's seat of the test vehicle to obtain motion and acceleration data.

The fifth percentile female dummy built to conform to federal Motor Vehicle Safety Standards, simulates a fifth percentile American female weighing 103 lbs. (includes coveralls and hat but not shoes) and 59 inches overall height. A female dummy was used because the driver



1 in.= 25.4 mm; 1 ft.= 0.305 m

PRECAST MEDIAN BARRIER DESIGN

FIGURE 1

FIGURE 2 - Test Barrier

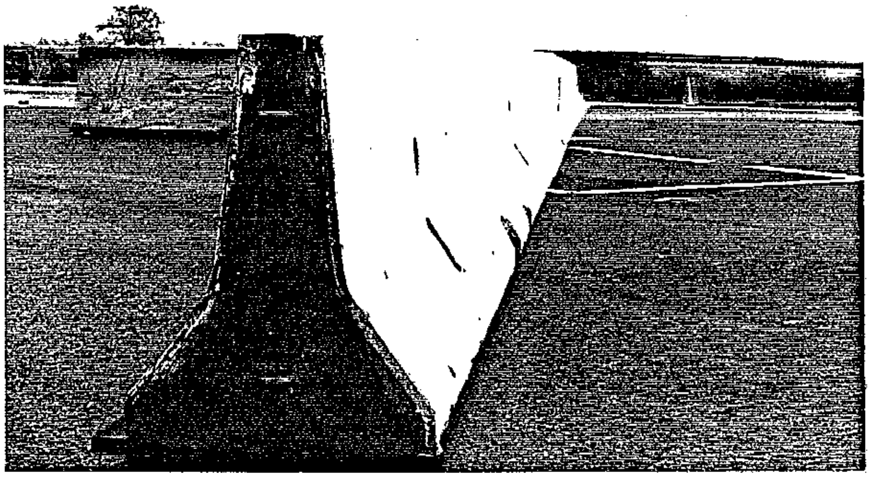
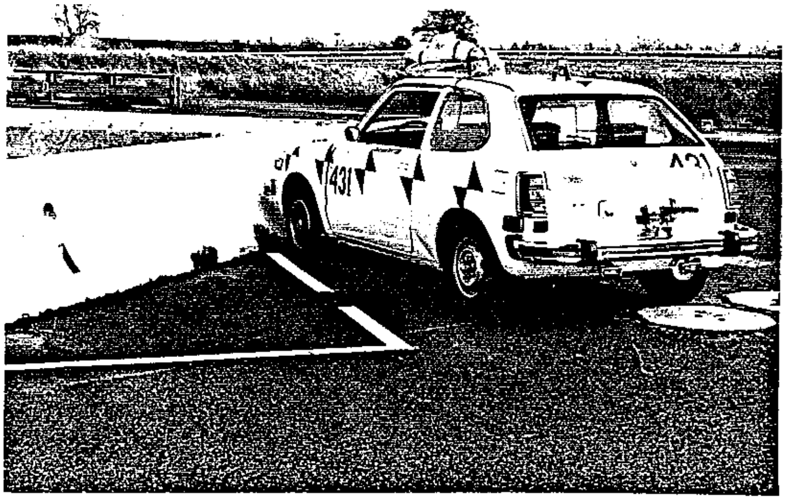


FIGURE 3 - Car Location With Respect to the
Barrier Before Impact



of the car in the accident which led to the study was a lightweight female. (Female dummies are available only in fifth percentile size). The dummy was not restrained.

3.1.5 Data Acquisition Systems

The impact event was recorded with several high speed movie cameras, one normal speed movie camera, one black and white sequence camera, and one color slide sequence camera. Three high speed cameras were mounted on a 35-foot high tower directly over the point of impact on the test barrier, two high speed cameras were mounted in the car to record the dummy's motions, and the remaining cameras were mounted on tripods. The test vehicle and test barrier were photographed before and after impact with a normal speed movie camera, a black and white still camera and a color slide camera. A film report of this test has been assembled using edited portions of the movie coverage. A detailed description of the photo-instrumentation is contained in Appendix B.

Three accelerometers were attached to the floor at the vehicle center of gravity. Accelerations in the longitudinal, lateral and vertical direction were recorded. The accelerometer data were used to calculate the occupant impact velocity to judge the risk to occupants. Three accelerometers were installed in both the head and chest of the dummy.

A sliding weight device was attached to the left side of the vehicle. Upon impact, the weight slid two feet forward and triggered a flash bulb. This was used as a rough check on the "rattlespace" time determined from accelerometer data which was used to calculate the occupant impact velocity. The rattlespace time is the time required for an object to move two feet forward with respect to the passenger compartment after the first instant of impact. A detailed description of the electronic instrumentation is contained in Appendix C.

3.2 Test Results, Test 431

(1860 lbs/27.4 mph/52°)

The Data Summary Sheet and photos taken during and after impact are shown in Figures 4 through 9. A film report showing Test 431 is available for viewing.

3.2.1 Impact Description

The left front bumper of the test vehicle impacted the 80 foot barrier at 48 feet from the end and 32 feet from the beginning of the barrier. The vehicle body contacted the barrier at initial impact (before the wheel) and then for a distance of 4 feet. The test vehicle rode up the face of the barrier and across the face while rolling clockwise, Figure 6. Maximum wheel climb on the parapet face was 2.25 feet. The vehicle continued off the barrier while rolling over onto its right side where it stopped, lying on the camera rack hung on the right window, Figure 7. The camera rack stopped the vehicle from continuing the rollover, which would possibly have caused more damage to the car and occupant.

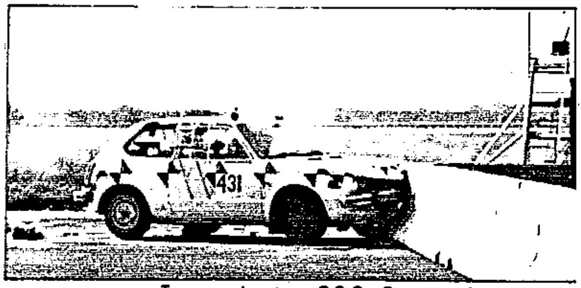
The vehicle remained on its right side at an angle of 69 degrees with respect to the center line of the barrier. The horn became stuck when the dummy struck the steering wheel and the dashboard.

The maximum 50 millisecond average value of lateral acceleration was -5.5 g's and the comparable value of longitudinal acceleration was -12.4 g's. The occupant impact velocity was 32.9 fps in the longitudinal direction.

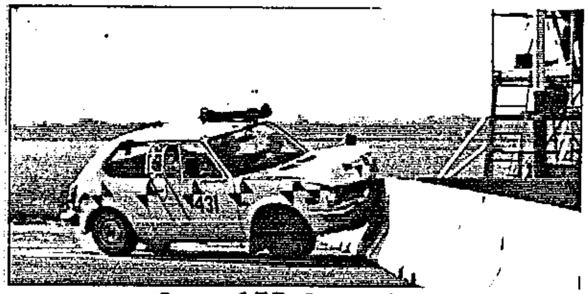
3.2.2 Vehicle Damage

Damage to the vehicle was relatively severe. Immediately after impact the left front quarter panel was crushed and buckled above the tire. The front bumper was crushed toward the right side of the vehicle. The

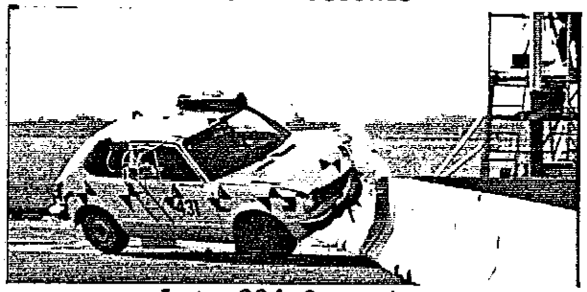
FIGURE 4 - Data Summary Sheet - Test 431



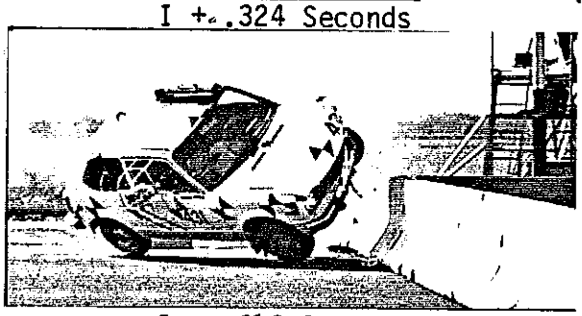
Impact + .029 Seconds



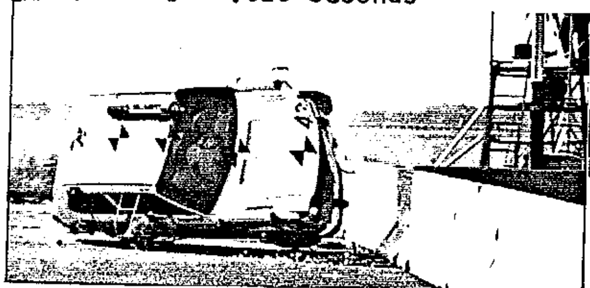
I + .177 Seconds



I + .324 Seconds



I + .619 Seconds



I + 1.209 Seconds

Test Date

January 29, 1985

Test Barrier

Type	Precast Reinforced Concrete
Shape	Safety Shape (New Jersey)
Length	80 ft. (4-20 ft. segments)

Test Vehicle

Model	1975 Honda Civic
Inertial Mass	1860 lbs.
Impact Velocity	27.4 mph (40.2 fps)
Impact Angle	52°

Test Dummy

Type	5th Percentile, Female
Weight/Height	103/lbs/59 in.
Position	Driver's Seat
Restraints	None

Test Data

Occupant Impact Velocity	32.9 fps long.
Max. 50 ms. avg. Vehicle Accel.	-12.4 g's long. -5.5 g's lat. 3.3 g's vert.
HIC	317
TAD/VDI	FL4/11FYEW3
Max. Roll/Pitch Yaw	71°/-2°/-12°
Permanent Barrier Displacement	1.75 in. Lateral

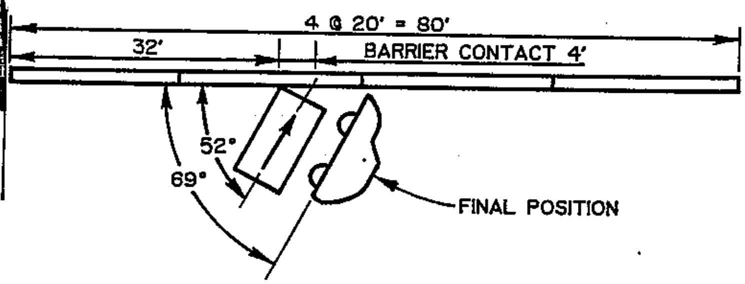


FIGURE 5 - Vehicle Damage

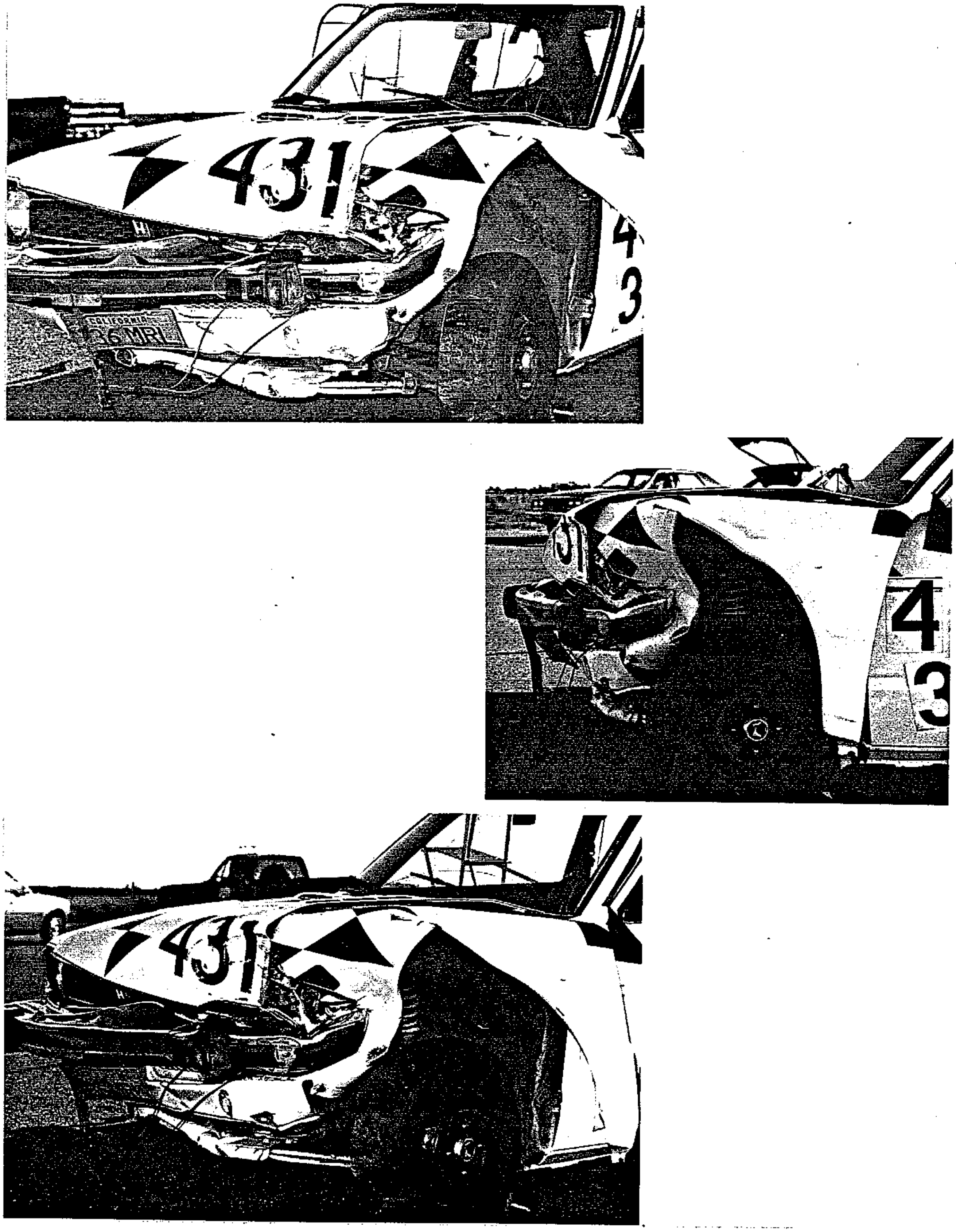
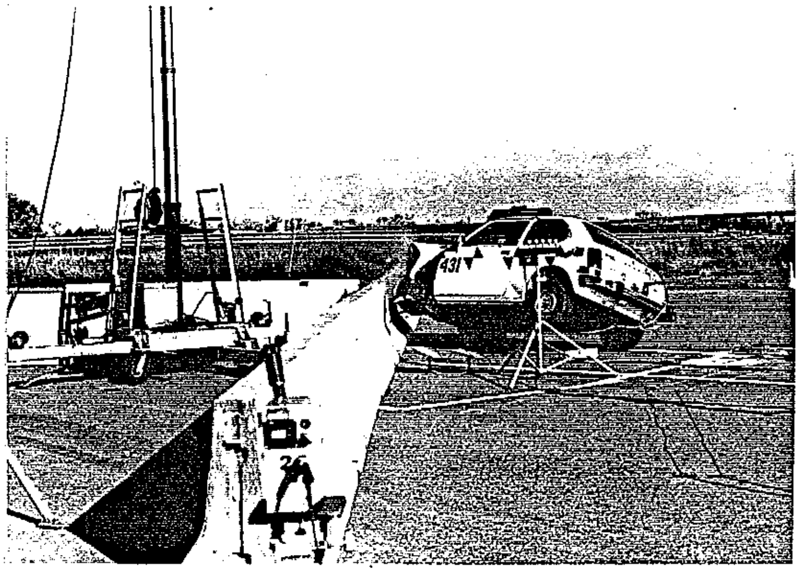
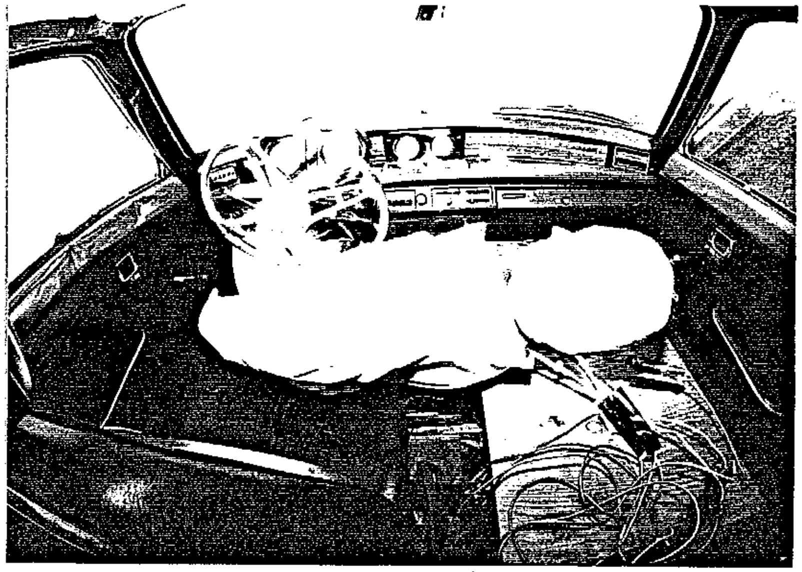


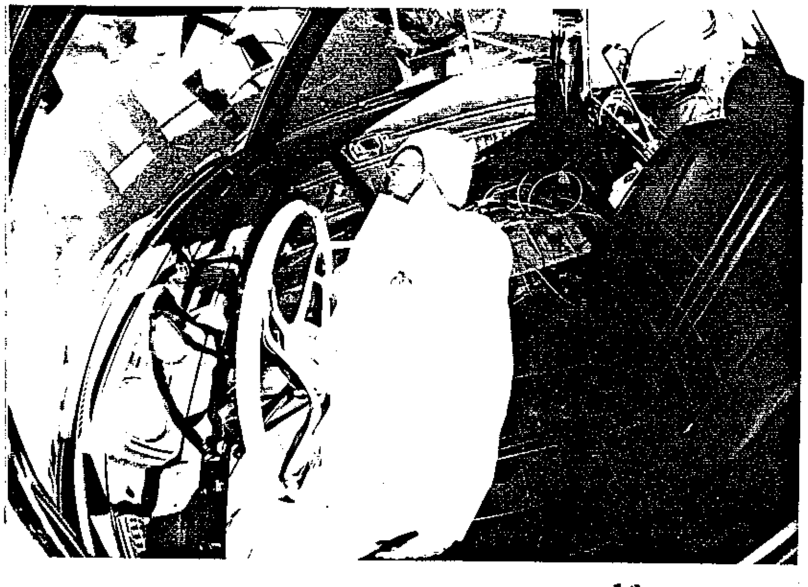
FIGURE 6 - Post Impact Views



Vehicle Climbing Barrier and Rolling During Impact

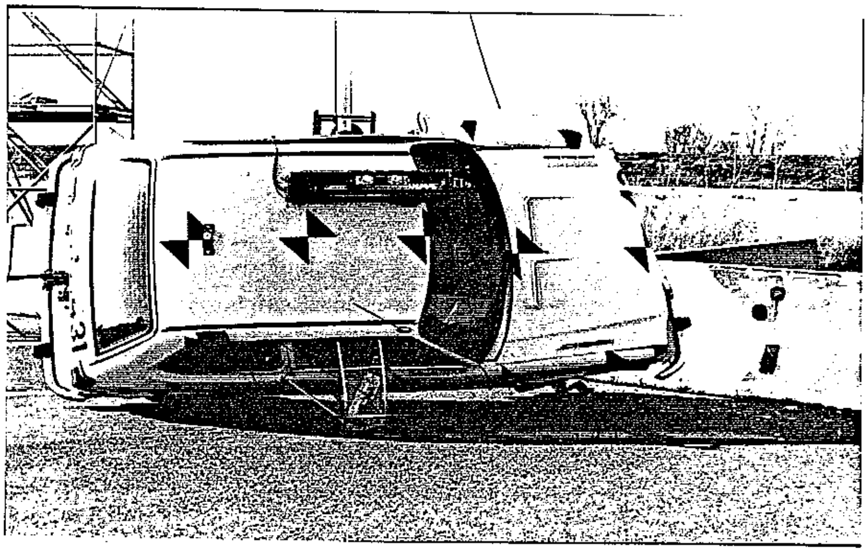


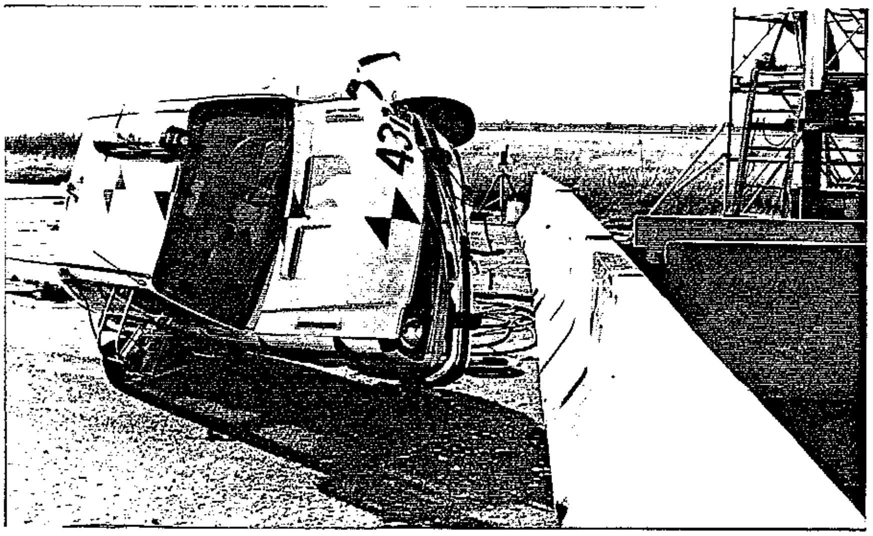
Dents in Door and Doorpost Due to Dummy Impact



Final Position of Dummy After Impact

Figure 7 - Car Location With Respect to the Barrier After Impact





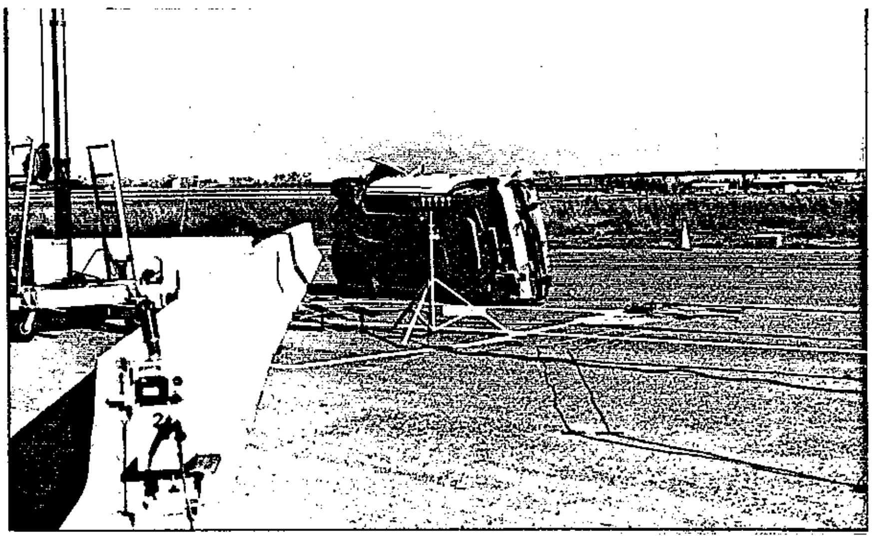
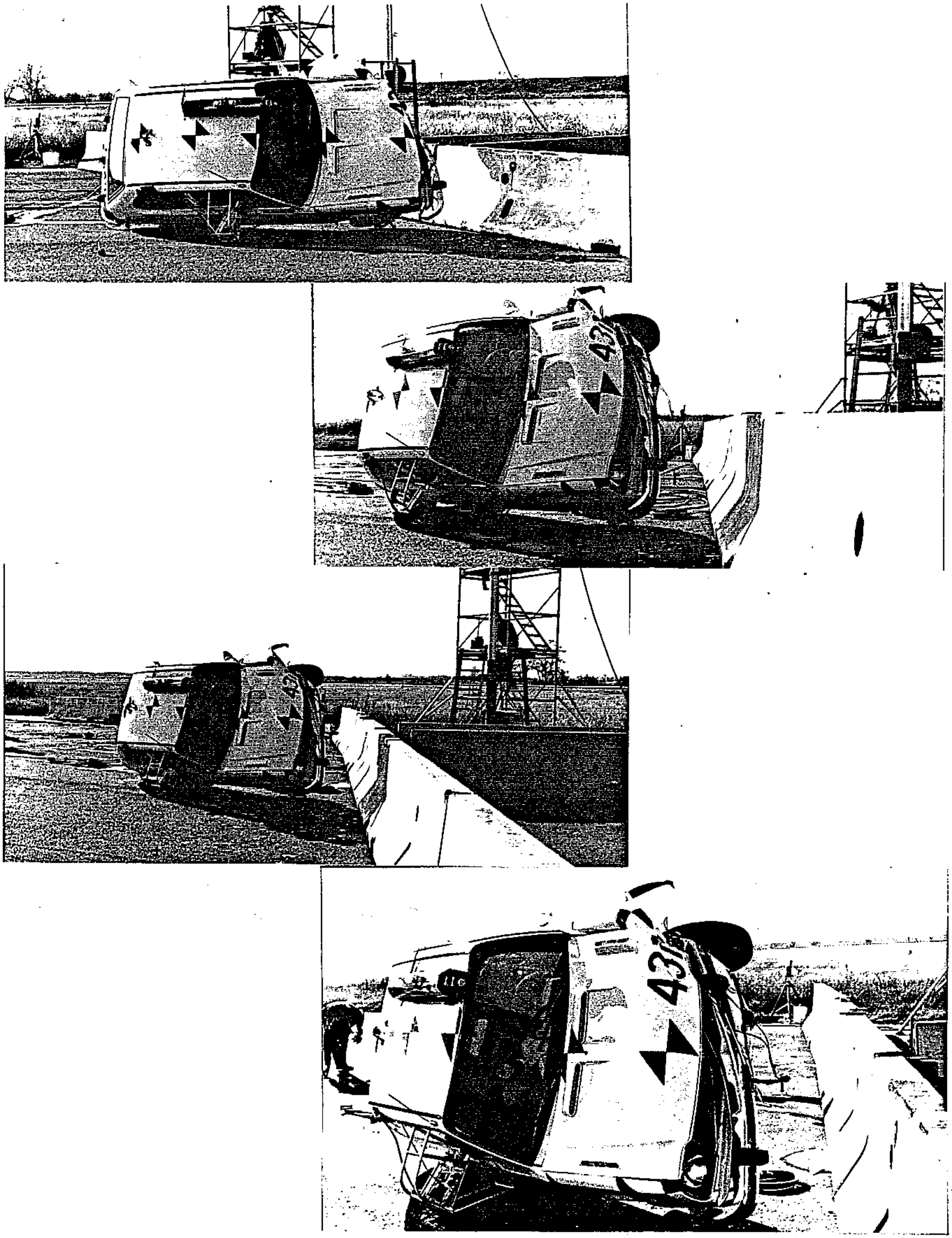


Figure 8 - Final Position of Vehicle After Impact



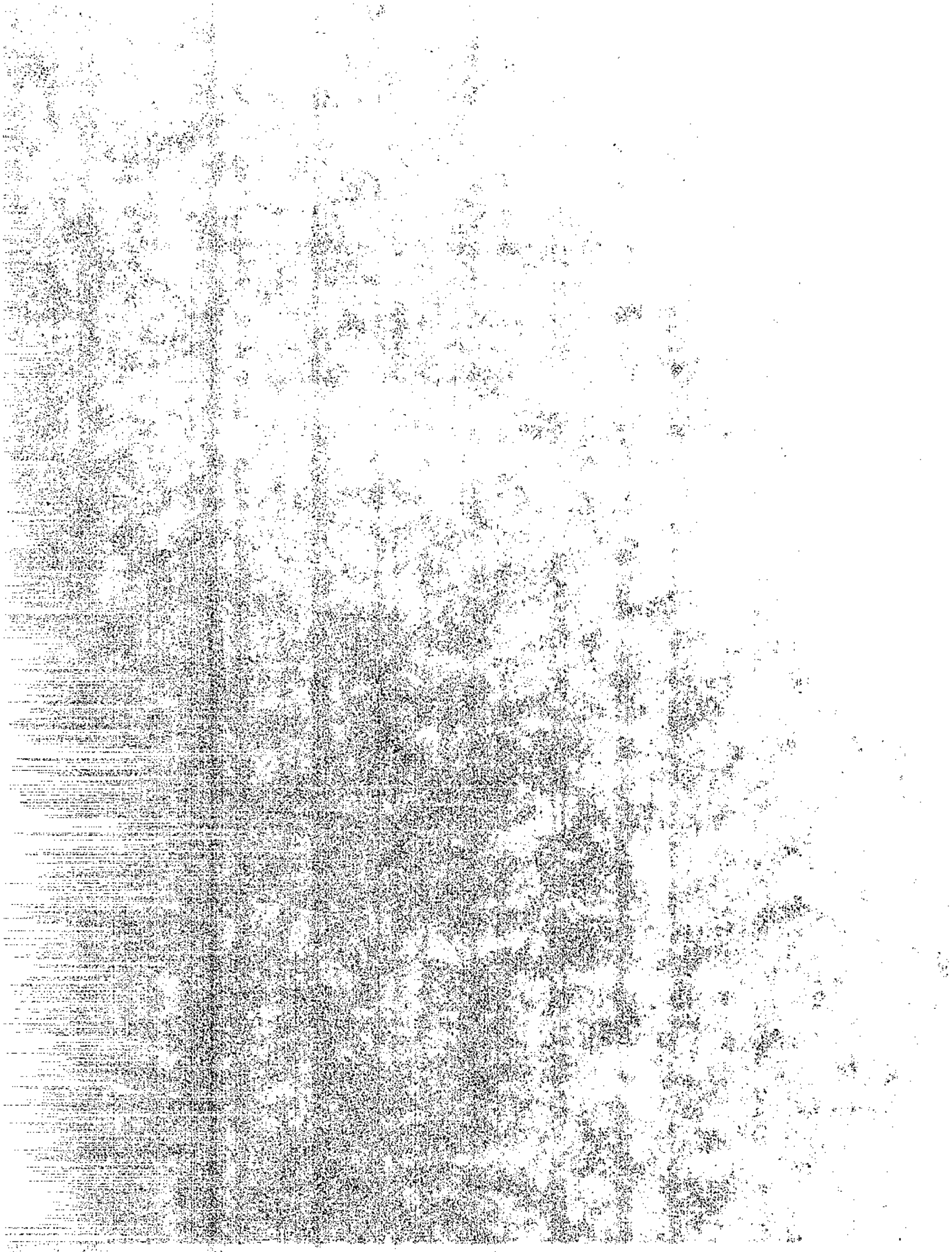
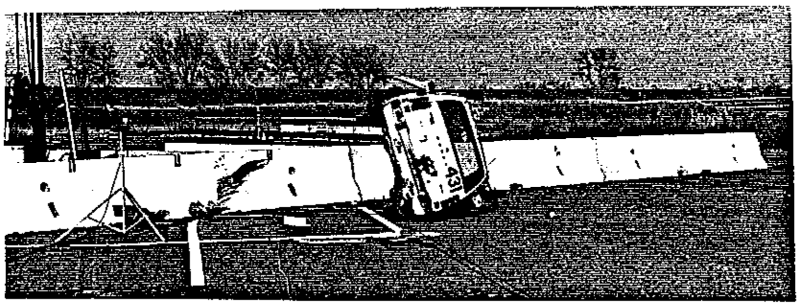
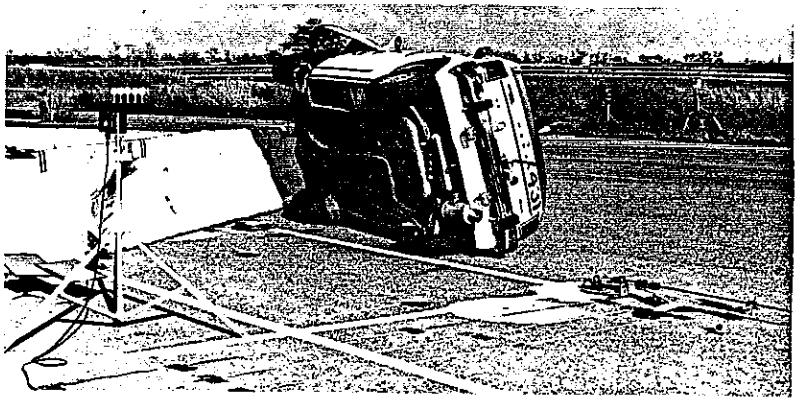


Figure 9 - Car Tire Marks on the Barrier





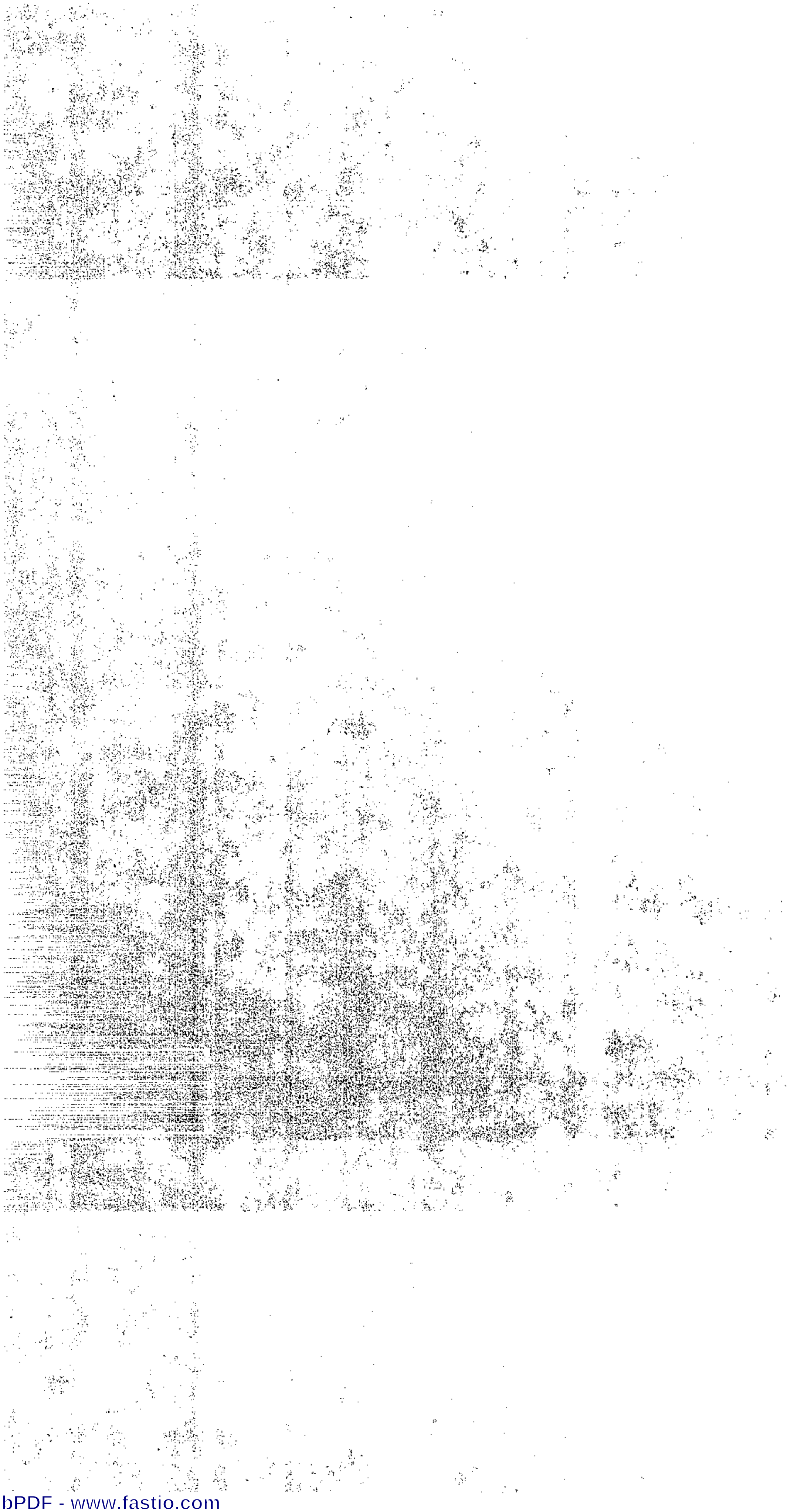
left side of the hood was crushed back and the hood opened. The left front headlight was crushed, and the front frame members under the engine were bent. The left front tire was flat, and the rim was scraped and bent, Figure 5. The left inside door panel was dented and bent forward (out) from impact by the dummy, Figure 6. The left door post from the upper front corner to 6 inches down its length, was struck by the dummy head, and bent 1/2-inch forward. During the redirection of the car, the left side was scraped. Paint from the side of the vehicle was transferred to the upper half of the barrier on an area about 20" long and 10 inches high. There was no intrusion of barrier or vehicle components into the passenger compartment. The steering wheel was bent about 6 inches toward the windshield from the impact of the dummy.

3.2.3 Barrier Damage

There was no evidence of any structural failure of the barrier. No visible cracks were detected. The only damage imparted to the barrier was a few scrapes and tire marks, Figure 9.

3.2.4 Dummy Response

During impact, the unrestrained 5th percentile female dummy, which was in the driver's seat, was thrown forcefully ahead into the steering wheel bending it and pushing it forward six inches from its original plane. The steering column was forced down. The dummy continued to move toward the left front corner of the car, and hit the left front door post, bending it. Then it was thrown to the right toward the passenger seat as the car rolled over to the right. After impact the dummy was laying across the front passenger seat with its legs wedged under the steering wheel, Figure 6.



3.3 Discussion of Test Results

3.3.1 General-Safety Evaluation Guidelines

In NCHRP Report 230(2), three evaluation factors are recommended for use in judging the crash test performance of median barriers. The three factors which will be discussed in the following sections are (1) structural adequacy, (2) occupant risk, and (3) vehicle trajectory. The results of this crash test will be compared with the evaluation factors in order to make judgments about the severity and seriousness of the test. The safety shape concrete barrier used for this test meets NCHRP Report 230(2) evaluation criteria when tested under the required standard conditions. Because the Test 431 impact speed and angle were unusual, test results neither qualify nor disqualify the barrier for use, but serve only as a measure of impact severity.

3.3.2 Structural Adequacy

The structural adequacy was evaluated by comparison of test results with the following pertinent criteria contained in Table 6 of NCHRP Report 230(2).

"A. Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.

D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic."

Criteria A and D - passed. The test barrier did not fail structurally. There were no visible cracks in the barrier. Other than tire marks, minor sheet metal scrapes, all of which would require minor maintenance

repair, the test barrier suffered no damage. No barrier debris intruded into the passenger compartment of the vehicle during the test.

There was no significant tilting or lateral barrier movement. The maximum permanent lateral barrier displacement was 1.75 inches.

Barrier damage was not expected because of the light weight of the test vehicle. All of these observations show that although the impact was severe, it did not cause enough damage to the barrier to represent a failed test, had the barrier itself been under investigation.

3.3.3 Occupant Risk

The occupant risk was evaluated by comparison of test results with the following criteria from Table 6 of NCHRP Report 230(2):

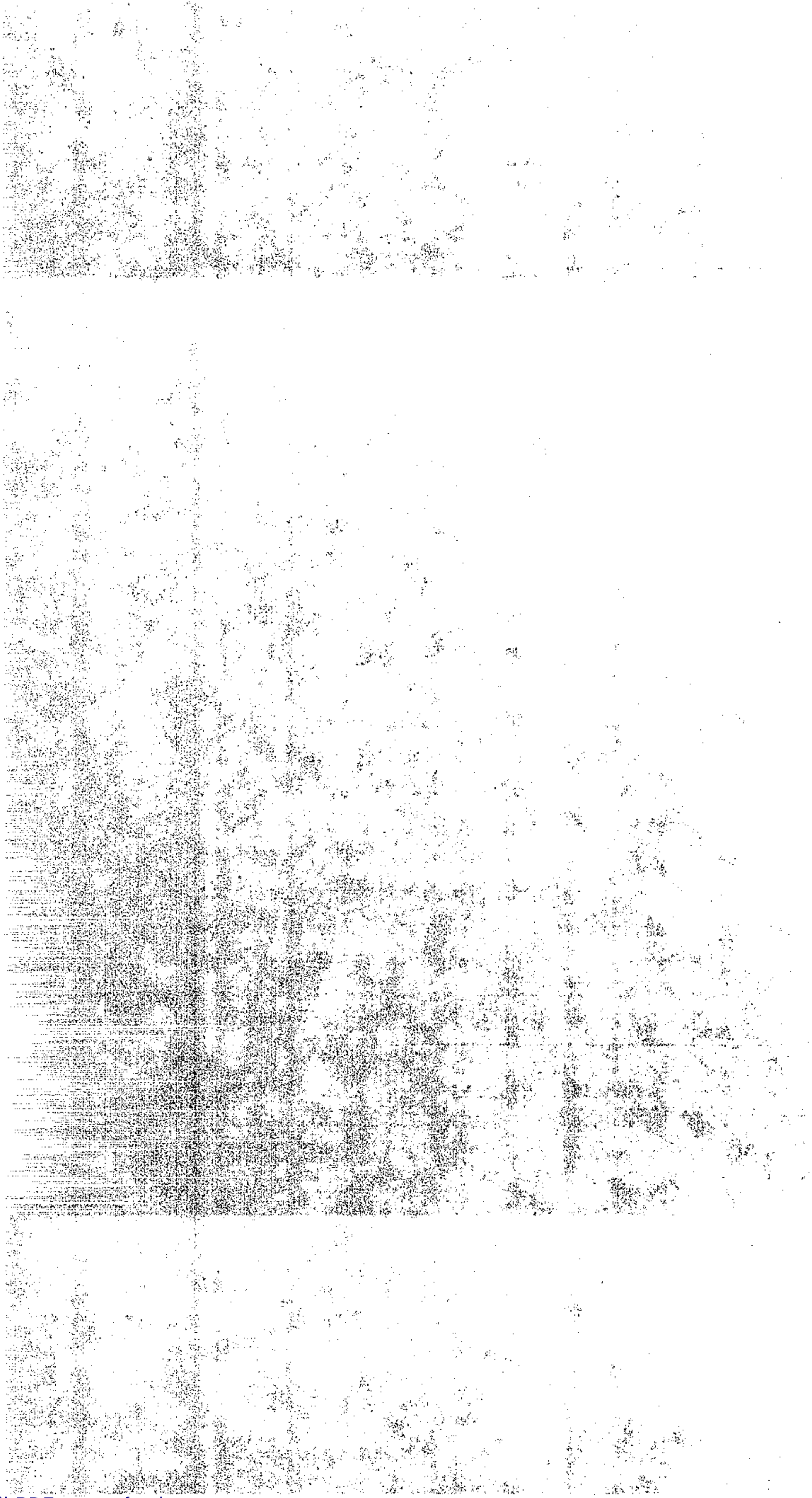
"E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.

F. Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle acceleration and 24 inch forward and 12 inch lateral displacements, shall be less than:

Occupant Impact Velocity - fps

Longitudinal	Lateral
$40/F_1 = 30$	$30/F_2 = 20$

and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than:



Occupant Ridedown Accelerations - g's

Longitudinal	Lateral
$20/F_3 = 15$	$20/F_4 = 15$

Where F_1, F_2, F_3, and F_4 are appropriate acceptance factors (The commentary in NCHRP Report 230 recommends that F_1, F_3, and $F_4 = 1.33$ and $F_2 = 1.50$).

G. (Supplementary) Anthropometric dummy responses should be less than those specified by FMVSS 208, i.e., resultant chest acceleration of 60g. Head Injury Criteria of 1000, and femur force of 2250 lb and by FMVSS 214, i.e., resultant chest acceleration of 60g, Head Injury Criteria of 1000 and occupant lateral impact velocity of 30 fps."

Criterion E - Failed.

During impact, and immediately after, the vehicle rode up the face of the barrier and across the face while rolling steadily clockwise to its right side. There was no intrusion of the passenger compartment when the car rolled over. If the camera rack had not been mounted outside the passenger door, the car would have continued to roll with the possibility of greater vehicle damage and more severe injuries to passengers.

Criterion F - Failed.

The longitudinal occupant impact velocity was 32.9 fps. The suggested maximum value is 30 fps longitudinal. This shows that the occupant impact velocity exceeded the suggested maximum value. The high longitudinal value illustrates the rapid stopping of the car. The lateral occupant impact velocity was not calculated because the high longitudinal accelerations controlled. The ride down accelerations were less than 15g for a 10 ms duration determined by inspection of the acceleration vs time plots.

The former method of evaluating occupant risk "impact severity", per TRC No. 191(3), was to calculate the maximum 50 millisecond average lateral and longitudinal vehicle accelerations for a 2250 lb/60 mph/15° test.

Recommended Maximum 50 ms Acceleration
TRC No. 191

Longitudinal	Lateral	
-10 g	-5 g	acceptable
- 5 g	-3 g	preferred

Actual 50 ms accelerations in Test 431 were - 5.5 g's lateral and -12.4 g's longitudinal. These values show that in the lateral direction, the test value was slightly higher than the limit, about 0.5 g, and in the longitudinal direction, the test value obviously exceeded the accepted limit. It should be noted that cars impacting concrete median barriers currently in use, equal or exceed the -5 g limit in the lateral direction in crash tests(4). It appears that the lateral acceleration cannot be reduced below -5 g's when a passenger vehicle impacts rigid barriers at angles of 15° to 25° and speeds of 60 mph.

Criterion G - Passed.

Dummy measurements are optional according to NCHRP Report 230. The Head Injury Criterion (HIC) was calculated to be 317 for test 431. This value is much less than the upper limit of 1000 which marks the threshold of serious injury or death due to head trauma. The maximum 3 ms dummy chest resultant acceleration was 50.8 g's, less than the 60 g limit. The test movie shows the dummy was thrown forcefully ahead into the steering wheel, bending and pushing it forward. The movie shows the dummy then hitting and denting the left front door post. It eventually fell to the right toward the passenger seat. If shoulder and lap belts had been worn correctly, there would have been virtually no chance of dummy impact with the interior of the passenger compartment.

This dummy behavior was not surprising under these tests conditions. It clearly illustrates the value of seat restraints which reduce or eliminate most injuries during an impact.

It should be noted that none of the above factors for evaluating the occupant risk are methods of predicting exact or specific injuries during impacts. NCHRP Report 230(2) states on page 12, "Whereas the highway engineer is ultimately concerned with safety of the vehicle occupant, the occupant risk criteria should be considered as the guidelines for generally acceptable dynamic performance. These criteria are not valid, however, for use in predicting occupant injury in real or hypothetical accidents". Also on page 3 it states, "Relationship between vehicle dynamics and probability of occupant injury and degree of injury sustained is tenuous, because it involves such important but widely varying factors as occupant physiology, size, seating position, restraint, and vehicle interior geometry and padding."

3.3.4 Vehicle Trajectory

The vehicle trajectory was evaluated by comparison of test results with the following criteria from Table 6 of NCHRP Report 230(2):

"H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.

I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device."

Criterion H - Possible Pass, Criterion I-Fail.

In test 431, the final resting position of the test vehicle after impact is shown on the Data Summary Sheet, Figure 4, in the Test Results section of this report and in Figures 6, 7 and 8. The test vehicle rode up the face of the barrier and across the face while rolling steadily clockwise to its right side where it rested, lying on the camera rack hanging on the right window. The vehicle remained on its right side at an angle of 69° with respect to the center line of the barrier. Rollovers do not meet the safety evaluation criteria for highway safety devices according to NCHRP Report 230. Hence, it is clear that this impact was extra hazardous due to the rollover.

3.3.5 Summary

The comparisons of test results with the evaluation factors in NCHRP Report 230 show that this was a severe impact. The vehicle rollover, high vehicle accelerations and dummy movement indicate that serious or fatal injuries could result from a crash under these test conditions, particularly if the passengers were unrestrained.

4. REFERENCES

1. "Traffic Manual", California Department of Transportation, 1977.

2. "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," Transportation Research Board, National Cooperative Highway Research Program Report 230, March 1981.

3. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", Transportation Research Board, Transportation Research Circular No. 191, February 1978.

4. Bronstad, M.E., L.R. Calcote, C.E. Kimball, Jr.; "Concrete Median Barrier Research, "Volume 2, Research, Southwest Research Institute, Report No. FHWA-RD-77-4, March 1976.

5. "U. S. and Foreign Passenger Car Specifications", Motor Vehicle Manufacturers Association, 1972-1981.

APPENDIX A: Test Vehicle Equipment and Cable Guidance System

The test vehicle was modified as follows for the crash tests:

The gas tank on the test vehicle was disconnected from the fuel supply line and drained. Shortly before the test, dry ice was placed in the tank as a safety precaution to drive out the gas fumes. A one-gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

Four 12-volt wet cell motorcycle storage batteries were mounted in the trunk. Two supplied power to the high speed camera and lamps mounted on the vehicle. The other pair of batteries operated a solenoid-valve braking system and other test equipment in the vehicle.

The gas pedal was linked to a small cylinder with a piston which opened the throttle. The piston was started by a hand thrown switch on the rear fender of the test vehicle. The piston was connected to the same CO_2 tube used for the brake system, but a separate regulator controlled the pressure.

A speed control device connected between the negative side of the ignition coil and the battery of the vehicle regulated the speed of the test vehicle based on speedometer cable output. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tape switches set a known distance apart and connected to a digital timer.

A cable guidance system directed the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path to a threaded coupler embedded in a concrete footing, passed through a guide bracket bolted to the spindle of the front wheel of the vehicle. A steel knockoff bracket, anchoring the end of the cable closest to the barrier to a concrete footing, projected high enough to knock off the guide bracket, thereby releasing the vehicle from the guidance cable before impact.

A micro switch was mounted below the front bumper and connected to the ignition system. A trip plate on the ground near impact triggered the switch when the car passed over it, thus opening the ignition circuit and cutting the vehicle engine before impact. This switch also released the sliding weight (mounted on top of the car) from an electromagnet so the weight was free to travel, slightly before the instant of impact.

A solenoid-valve actuated CO_2 system controlled remote braking after impact or emergency braking any other time. Part of this system was a cylinder with a piston which was attached to the brake pedal. The pressure operating the piston was set during trial runs to stop the test vehicle without locking up the wheels. When activated, the brakes were applied in less than 100 milliseconds.

The remote brakes were controlled at the console trailer. A cable ran from the console trailer to the electronic instrumentation trailer. From there, the remote brake signal was carried on one channel of the tether line which was connected to the test vehicle. Any loss of continuity in these cables activated the brakes and cut off the ignition automatically. Also, when the brakes were applied by remote control from the console trailer, the ignition was automatically cut off.

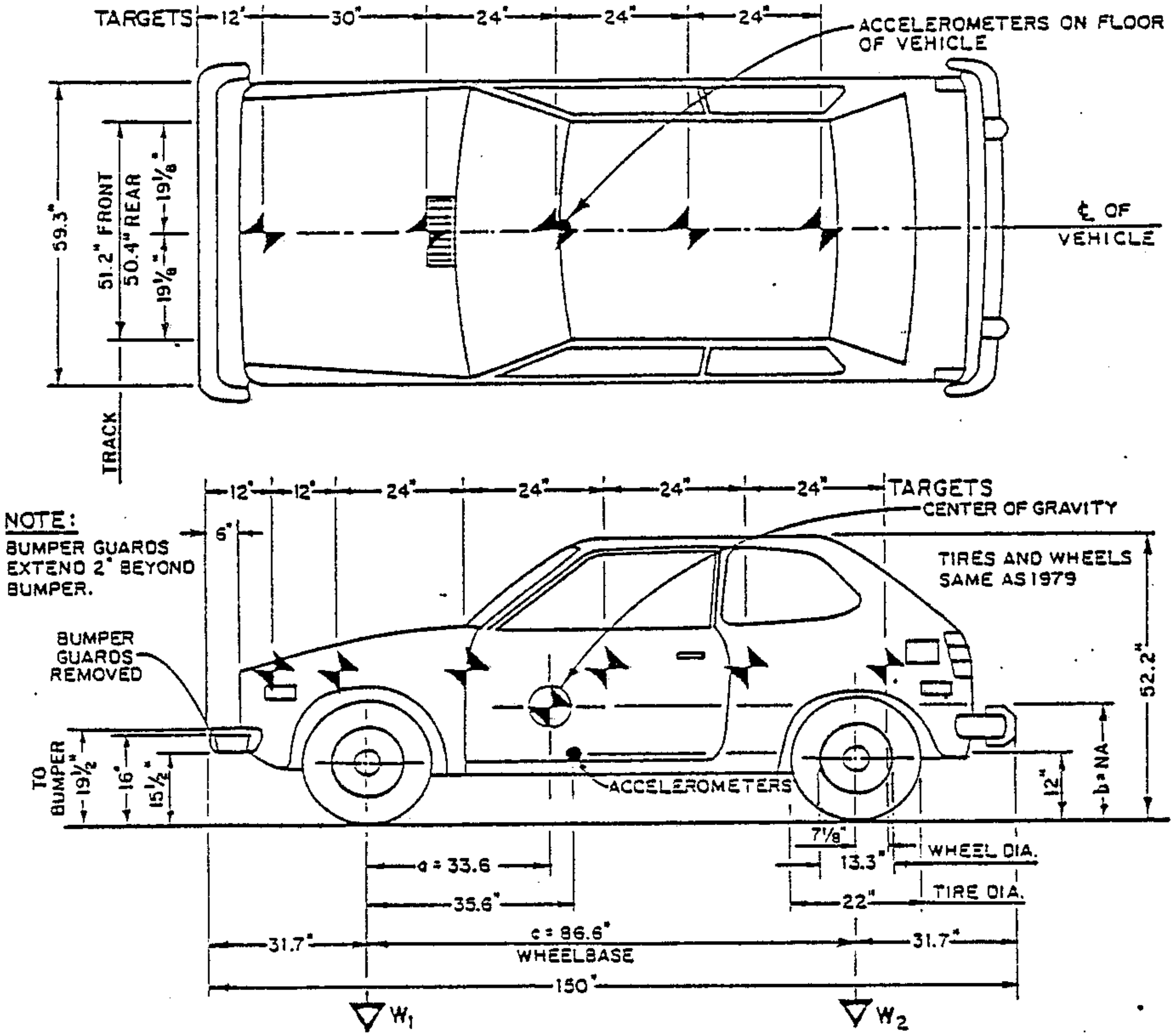
Figure A-1 shows the vehicle dimensions. Dimensions were taken from Reference(5) or measured.

FIGURE A1

TEST NO. 431

TEST DATE: 1-29-85

VEHICLE - 1975 HONDA CIVIC HATCHBACK



WEIGHT-lb	TEST INERTIAL	DUMMY	GROSS STATIC
W_1	1139	—	—
W_2	721	—	—
W_T	1860	103	1963

$$a = \frac{W_2(c)}{W_1 + W_2}$$

CAR DIMENSIONS

APPENDIX B: Photo-Instrumentation

Several high speed movie cameras recorded the impact during the crash test. The types of cameras and their locations are shown in Figure B1. These cameras were connected by cables to a console trailer near the impact area which contained eight 12-volt batteries. Most of the cameras were turned on remotely from a control panel on the trailer. One camera was turned on directly at the camera by a crew member. The camera in the test vehicle was triggered by removing a "key" from a switch, mounted on the rear bumper. A tether line, staked at one end, was attached to the key, and pulled it out after the car traveled 300 feet.

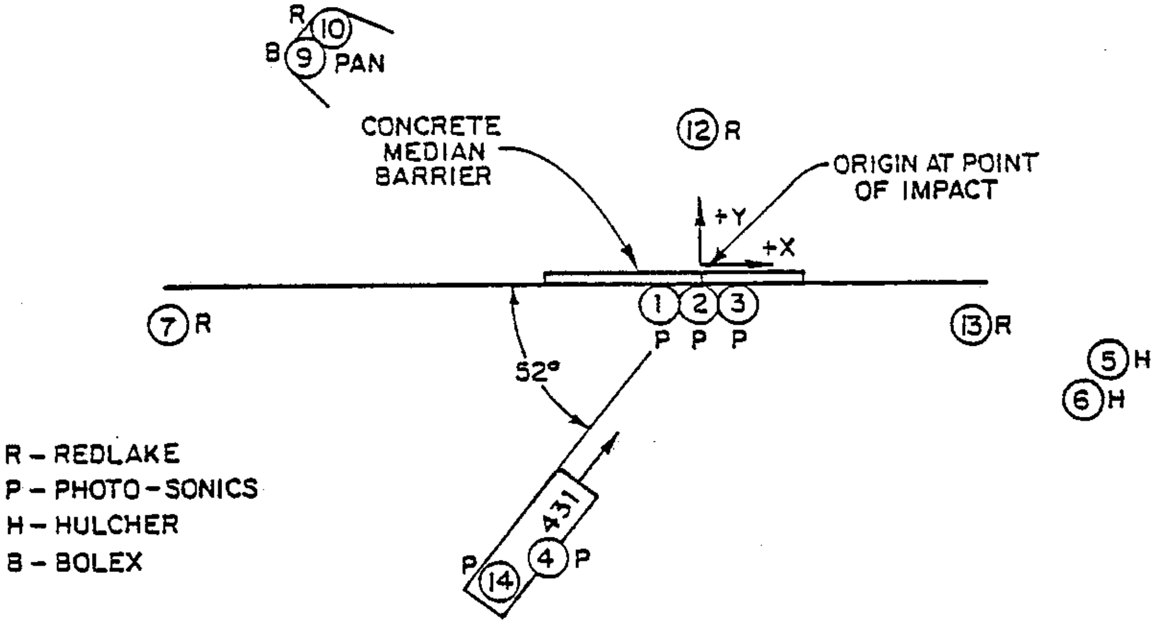
Following are the pretest procedures that were needed for film data reduction on a Vanguard Motion Analyzer:

Butterfly targets were attached to the top and sides of the test vehicle. The target locations are shown in Figure A-1. The targets established scale factors and horizontal and vertical alignment. The test barrier railing was targeted with black and white tape also.

Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle to barrier contact, (b) the application of the vehicle's brakes, and (c) beginning and end of sliding weight travel. The impact flashbulbs have a delay of several milliseconds before lighting up.

Five tape switches, placed at 10 foot intervals, were attached to the ground perpendicular to the path of the impacting vehicle near the concrete barrier. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of most of the data cameras. The flashing bulbs were used to correlate the cameras with the impact events; and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure B2.

FIGURE B1



CAMERA DATA AND LAYOUT

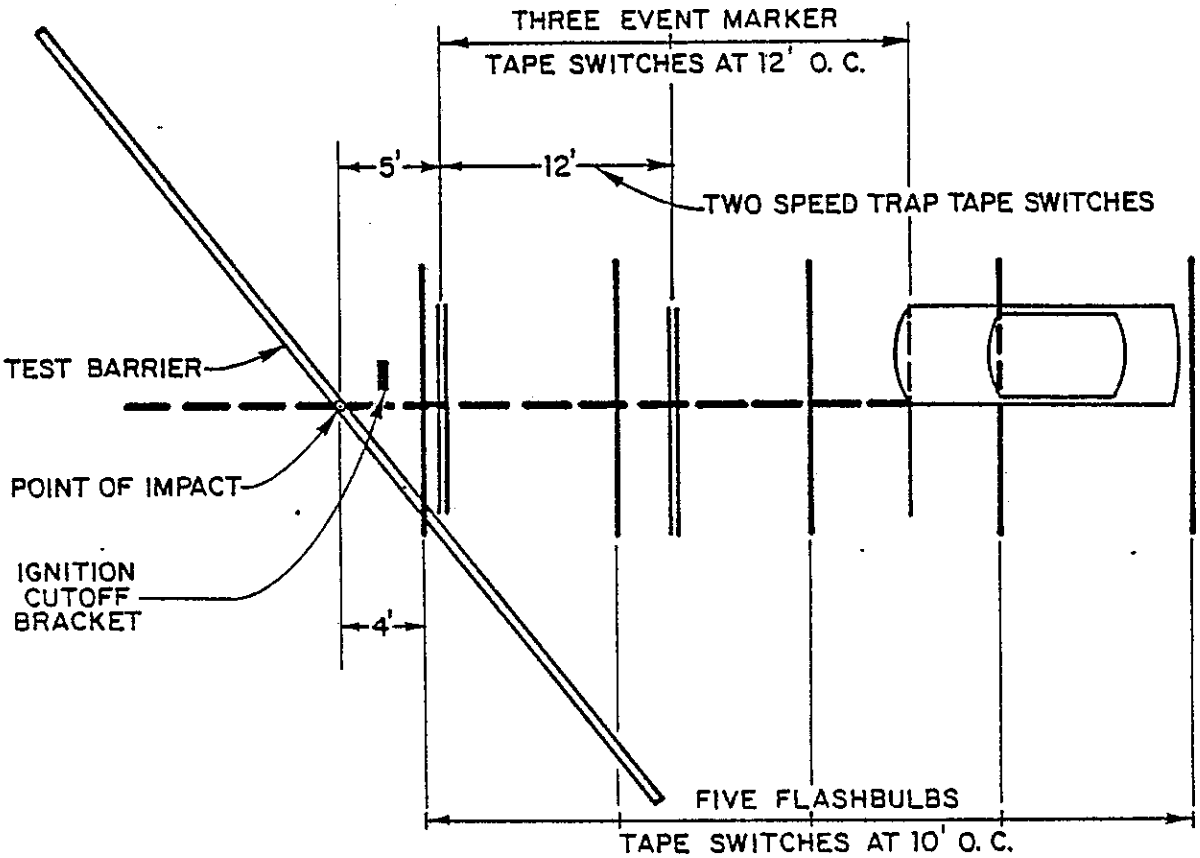
Cam No	Film (mm)	Camera Type	Rate Fr/sec	Lens (mms)	Lens Opng 411	Lens Opng 412
1	16	Photo-Sonics	400	13	4.5	3.5
2	16	Photo-Sonics	400	13	4.5	3.5
3	16	Photo-Sonics	400	13	4.5	3.5
4	16	Photo-Sonics	200	13	6.3	4.0
5	35	Hulcher	20	135	2.4	2.8
6	70	Hulcher	20	300	.6.3	4.5
7	16	Redlake-Locam	400	105	4.0	2.5
9	16	Bolex	24	25	16.0	11.0
10	16	Redlake-Locam	400	30	4.5	2.5
12	16	Redlake-Locam	400	12.5	4.5	2.5
13	16	Redlake-Locam	400	50	6.3	2.5
14	16	Photo-Sonics	200	7.5	2.0	1.8

Notes:

1. The frame rate listed is the nominal value.
2. All cameras were on tripods except 1, 2 & 3 on a 35 ft. tower, and 4, 14 in the car. Cameras 9, 10 were on a scaffold.

All high speed cameras had timing light generators which exposed red timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships.

FIGURE B2



TAPE SWITCH LAYOUT
TEST 431

APPENDIX C: Electronic Instrumentation and Data

Nine accelerometers measured acceleration. Three unbonded strain gage accelerometers (Statham) were at the longitudinal and lateral center of gravity of the cars. One each was oriented in the longitudinal, lateral, and vertical direction. These accelerometers were mounted on a small rectangular steel plate which was bolted to another steel bracket that was welded to the floorboard. Figure A1 shows the exact location of the accelerometers. Table C1 gives information on the instrumentation. Figure C1 shows the sign conventions for the vehicle accelerometers. Three piezoresistive accelerometers (Endevco) were mounted in the head cavity of the dummy. One each was oriented in the longitudinal, lateral, and vertical direction. Similarly, three accelerometers were mounted in the chest cavity of the dummy.

Data from the accelerometers in the test vehicle were transmitted through a 1000 foot Belden #8776 umbilical cable connecting the vehicle to a 14-channel Hewlett Packard 3924C magnetic tape recording system. This recording system was in an instrumentation trailer at the test control area.

Three pressure-activated tape switches were placed on the ground in front of the test barrier. They were spaced at carefully measured intervals of 12 feet. When the test vehicle tires passed over them, the switches produced sequential impulses or "event blips" which were recorded concurrently with the accelerometer signals on the tape recorder and served as "event markers". A tape switch on the front bumper of the car closed at the instant of impact and activated flash bulbs mounted on the car. The closure of the bumper switch also put a "blip" or "event marker" on the recording tape. A time cycle was recorded continuously on the tape with a frequency of 500 cycles per second. The impact velocity of the vehicle could be determined from the tape switch impulses and timing cycles. Two other tape switches connected to digital readout equipment were placed 12 feet apart

TABLE C1

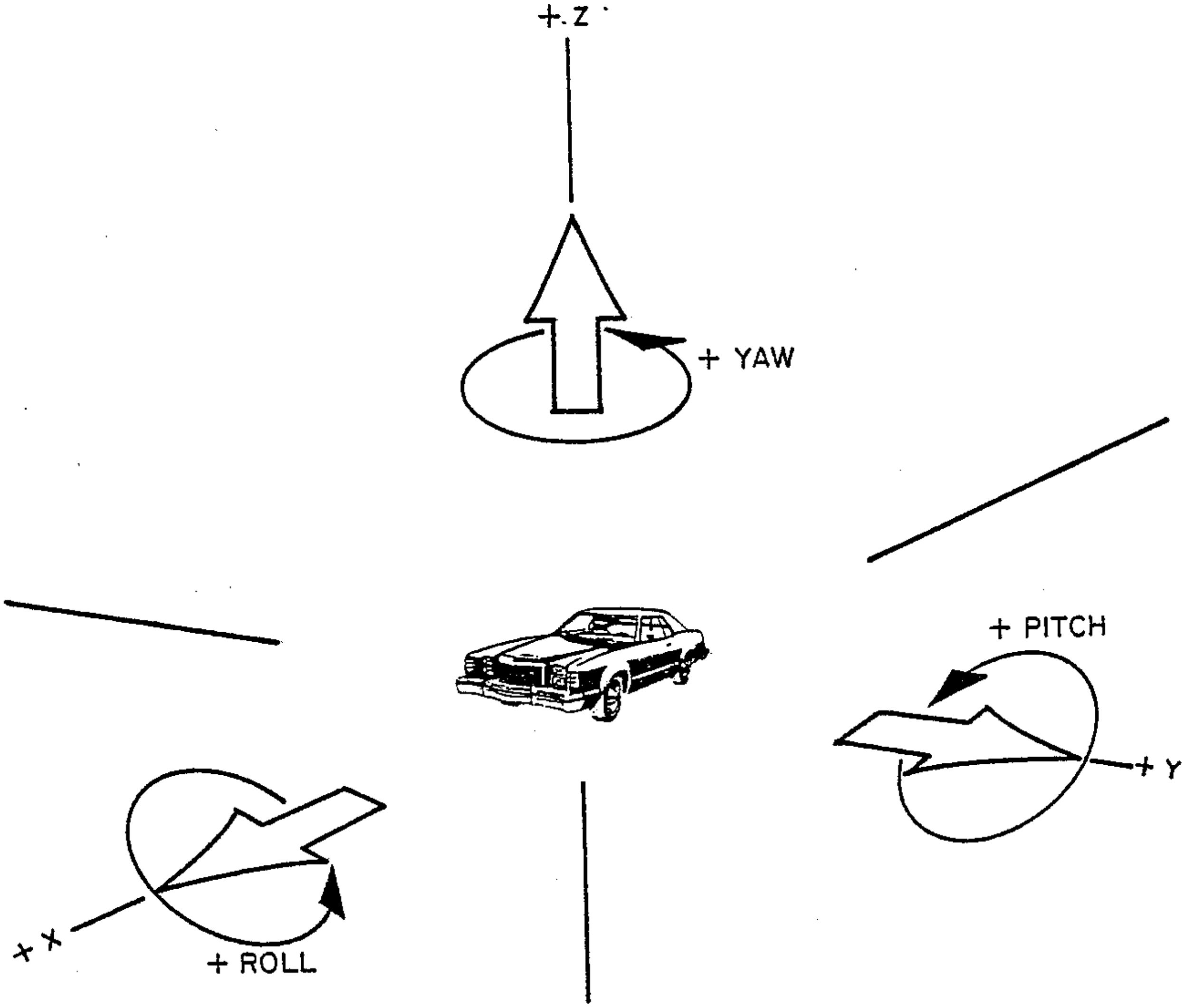
ACCELEROMETER INFORMATION

Channel Number	Instrument Number	Range	Calib. Magnit.	Location	Orientation
1 HP	ACCEL 587	50 g	20	Veh.c.g.	Long.
2 HP	588	50 g	20	Veh.c.g.	Lat.
3 HP	589	50 g	20	Veh.c.g.	Vert.
4 HP	590	100 g	50	Dummy Chest	Long.
5 HP	591	100 g	50	Dummy Chest	Lat.
6 HP	1029	100 g	50	Dummy Chest	Vert.
7 HP	EW 21	200 g	50	Dummy Head	Long.
8 HP	EW 46	200 g	50	Dummy Head	Lat.
9 HP	EW 69	200 g	50	Dummy Head	Vert.

Notes:

1. Channels 1-9 HP were on the Hewlett Packard tape recorder.
2. Accelerometer data were on Channels 1-9 HP.

FIGURE C1



VEHICLE ACCELERATIONS SIGN CONVENTION

just upstream from the test barrier specifically to determine the impact speed of the test vehicle immediately after the test. The tape switch layouts are shown in Appendix B in Figure B2.

After the test, the accelerometer data were played back from the tape recorder through a Visicorder which produced an oscillographic trace (line) on paper for each channel of the tape. Each paper record contained a curve of data from one accelerometer, signals from the event marker tape switches and bumper impact switch, and the time cycle markings.

Some of the data from the accelerometers mounted on the test vehicle contained high frequency spikes. All the test vehicle data were filtered at 100 hertz and 12 db per octave cutoff with a Krohn-Hite filter to facilitate data interpretation and reduction by hand. The smoother resultant curves gave a good representation of the overall acceleration of the vehicle without significantly altering the amplitude and time values of the acceleration pulses. The data from the accelerometers in the dummy's head were smoother and were not filtered.

The Visicorder paper records of accelerometer data served as a check on the main data reduction method described below.

All accelerometer data were processed on a Norland Model 3001 waveform analyzer which was the primary means of data reduction. The analyzer digitized and manipulated the raw data, printed test results, and plotted various curves. These data curves are shown in Figures C2 through C12 and include the accelerometer records from the car and dummy.

Figure C2 shows the Vehicle Accelerations; Figures C5 and C6 show the Dummy Head and Chest Accelerations. Blown up Views of Acceleration vs Time are shown in Figure C7, Vehicle Longitudinal; Figure C8, Vehicle Lateral; Figure C9, Dummy Head Resultant; and Figure C10, Dummy Chest Resultant. Figures C3 and C4 show Vehicle Longitudinal Accelerations, Velocity, and

FIGURE C2 - Vehicle Accelerations

TEST NUMBER

431.00

CONC.

MEDIAN

BARRIER

JAN 29 1985

MAX. 50 MS

AVER. ACCEL.

FOR CAR (G)-

VERTICAL---

3.0540

FROM TIME(S)

5.5500E-02

LONGITUDINAL

-12.373

FROM TIME(S)

4.0000E-02

LATERAL

-5.5364

FROM TIME(S)

3.1500E-02

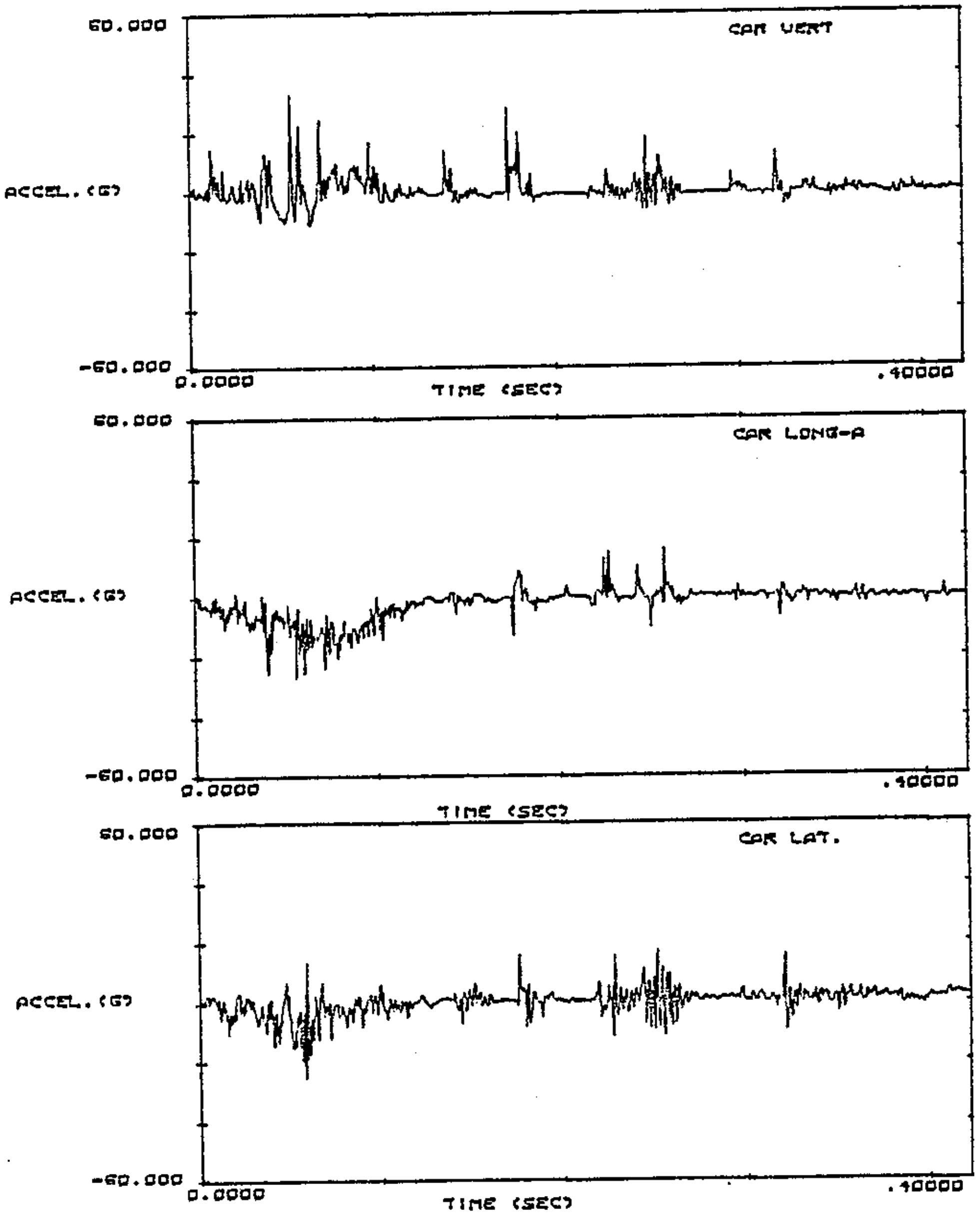


FIGURE C3 - Vehicle Longitudinal Acceleration, Velocity, Distance and Kinetic Energy vs. Time

TEST NUMBER

431.00

CONC.

MEDIAN

BARRIER

JAN 29 1985

CAR WEIGHT

(POUNDS)-

1860.0

MASS(SLUGS)-

5.7764E-02

KINETIC

ENERGY (KE)

EQUALS 1/2

MASS TIMES

THE SQUARE

OF THE VEL.

AT IMPACT

VEL. (FPS)-

40.187

VEL. (MPH)-

27.400

K.E. (FT-K)-

46.643

DISSIPATED

KE (AT END

OF ANALYSIS)

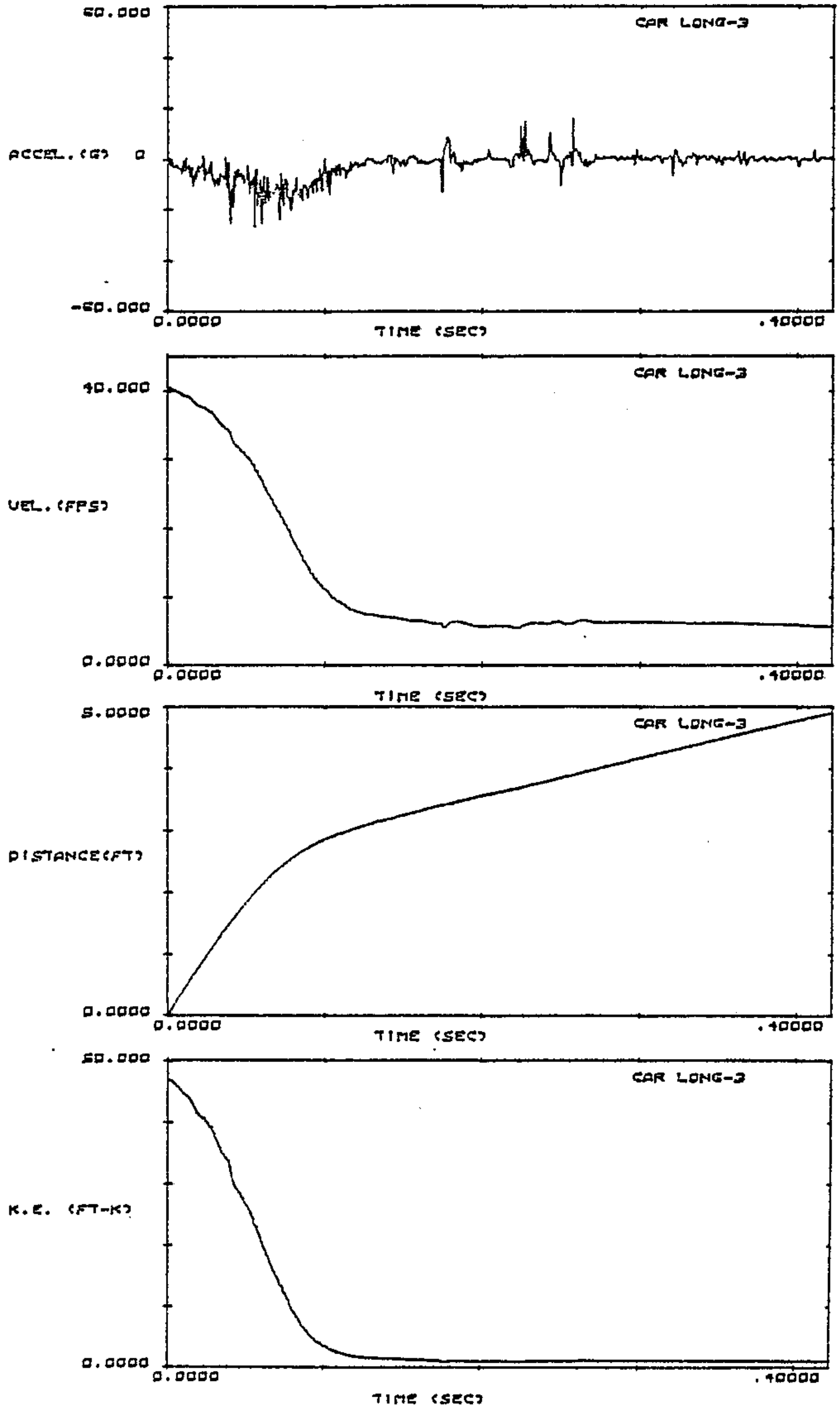


FIGURE C4 - Vehicle Motion vs Time to Find Occupant Impact Velocity; Vehicle Velocity and Kinetic Energy vs Distance.

TEST NUMBER
431.00
CONC.
MEDIAN
BARRIER

JAN 29 1985

CAR IMPACT
VELOCITY
(FPS)-
40.187

AT CAR
DISTANCE(FT)
3.1039
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
32.853
OCCURS AT
.12700
SEC. AFTER
CAR IMPACT

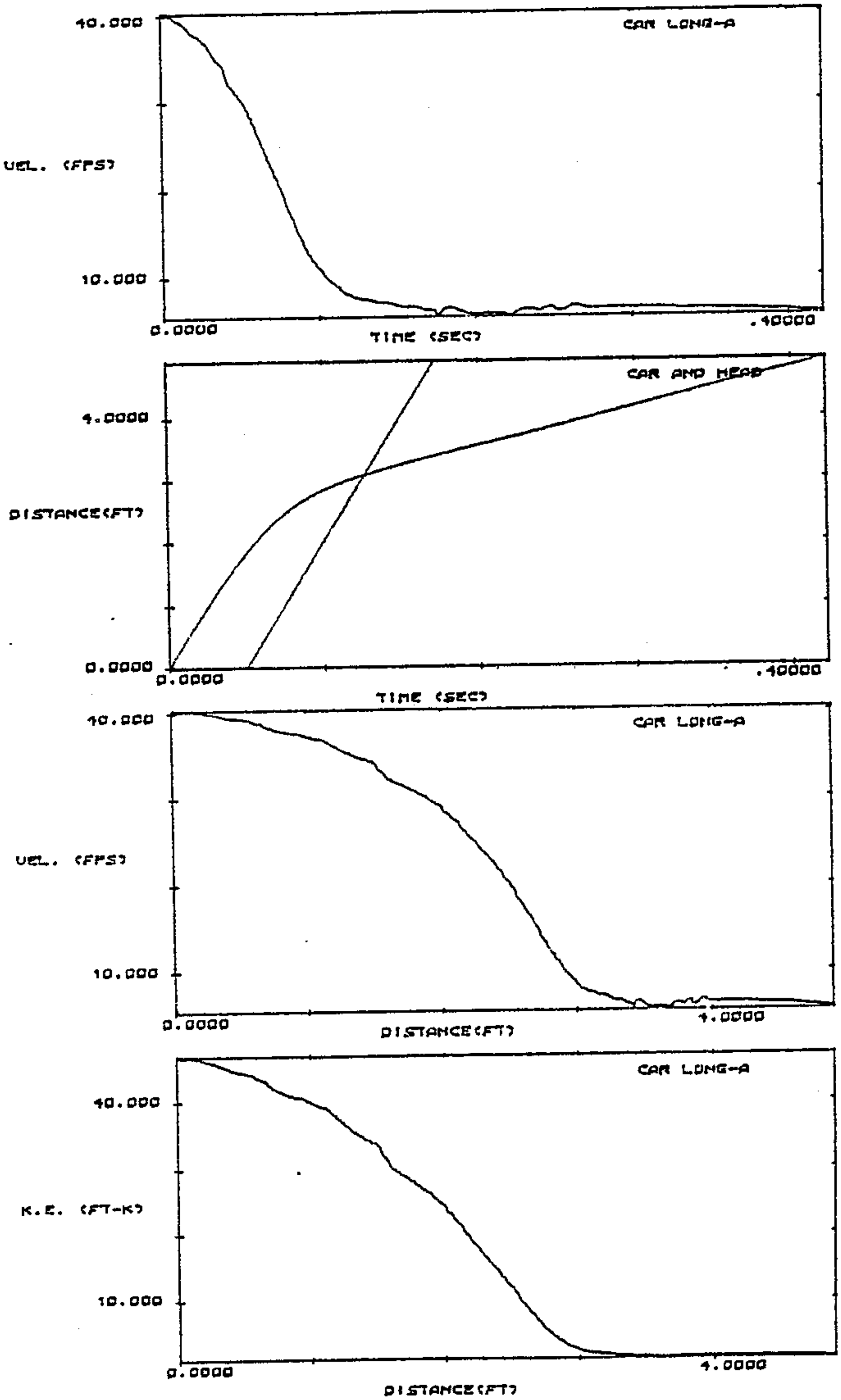


FIGURE C5 - Dummy Head Accelerations vs Time.

TEST NUMBER
431.00
CONC.
MEDIAN
BARRIER
52 DEGREES

JAN 29 1985

MAXIMUM
50 MS AVER.
DUMMY HEAD
RESULTANT
ACCEL. (G)-
30.532
FROM TIME(S)
8.6500E-02
TO TIME(S)
.13650

HEAD INJURY
CRITEREON-
316.72
FROM TIME(S)
9.5500E-02
TO TIME(S)
.12950

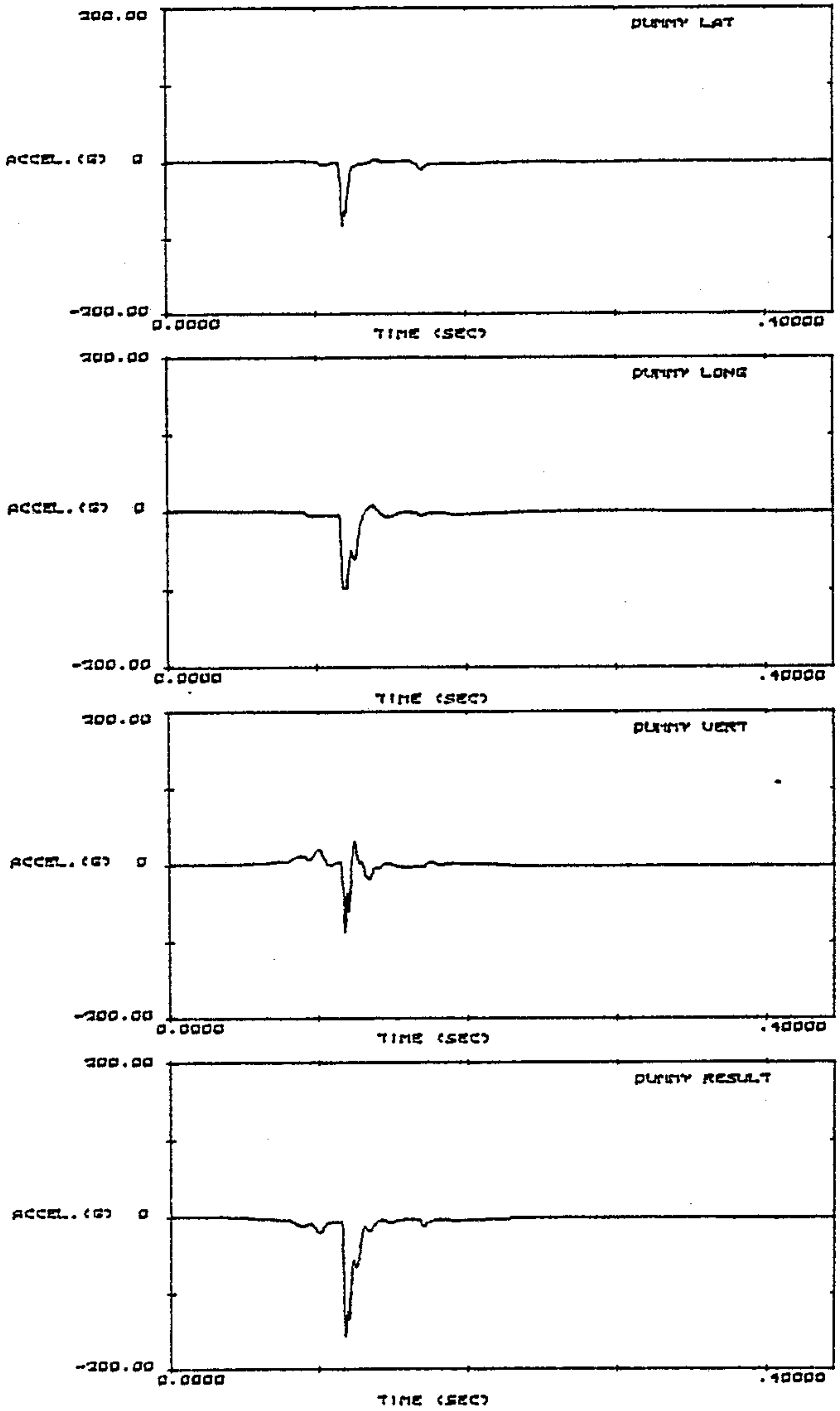


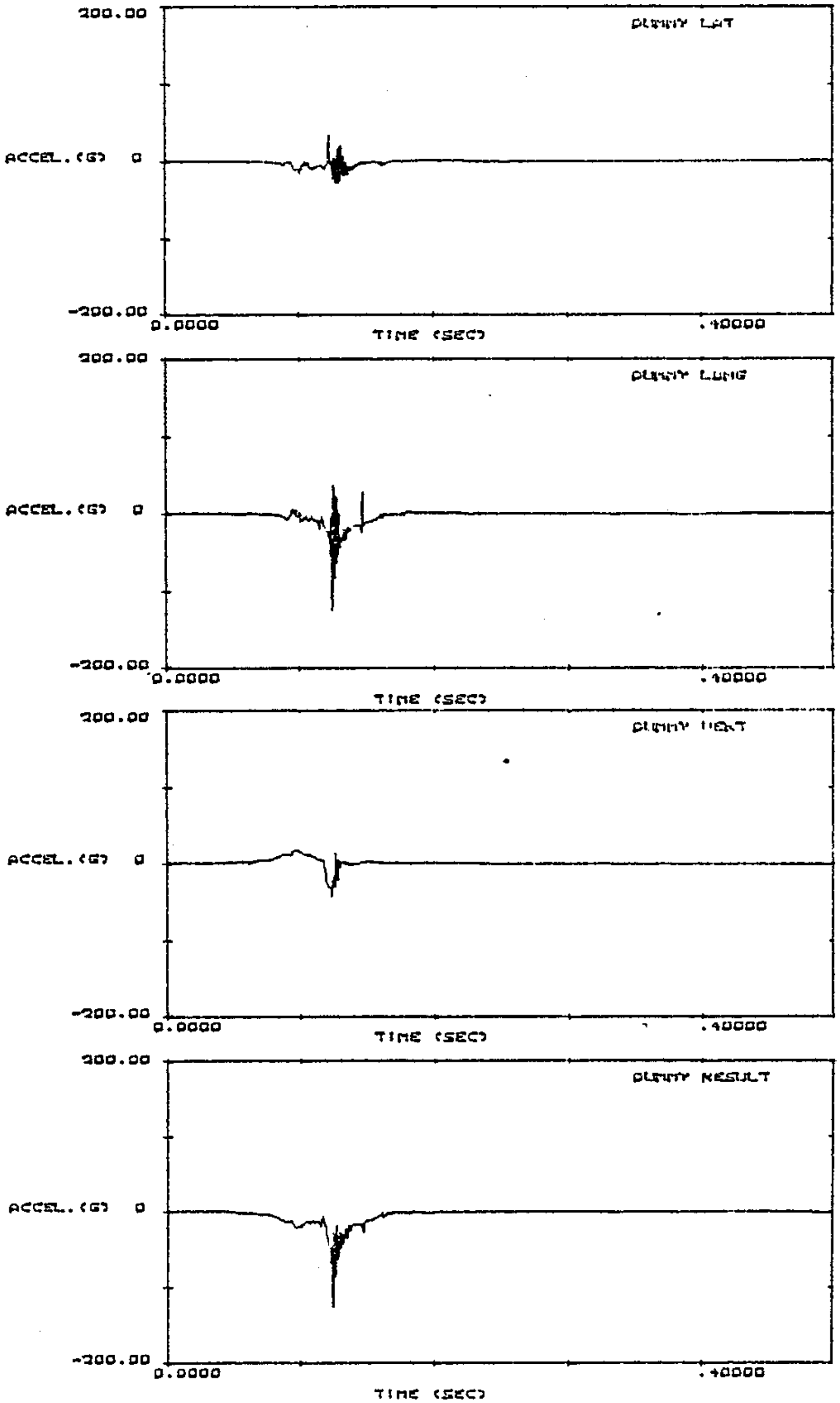
FIGURE C6 - Dummy Chest Accelerations vs Time.

TEST NUMBER
431.00
CONC.
MEDIAN
BARRIER
52 DEGREES

JAN 29 1985

MAXIMUM
50 MS AVER.
DUMMY CHEST
RESULTANT
ACCEL. (G)-
25.142
FROM TIME(S)
9.4500E-02
TO TIME(S)
.14450

CHEST INJURY
CRITEREON-
163.22
FROM TIME(S)
9.4000E-02
TO TIME(S)
.14850



TEST NUMBER
431.00

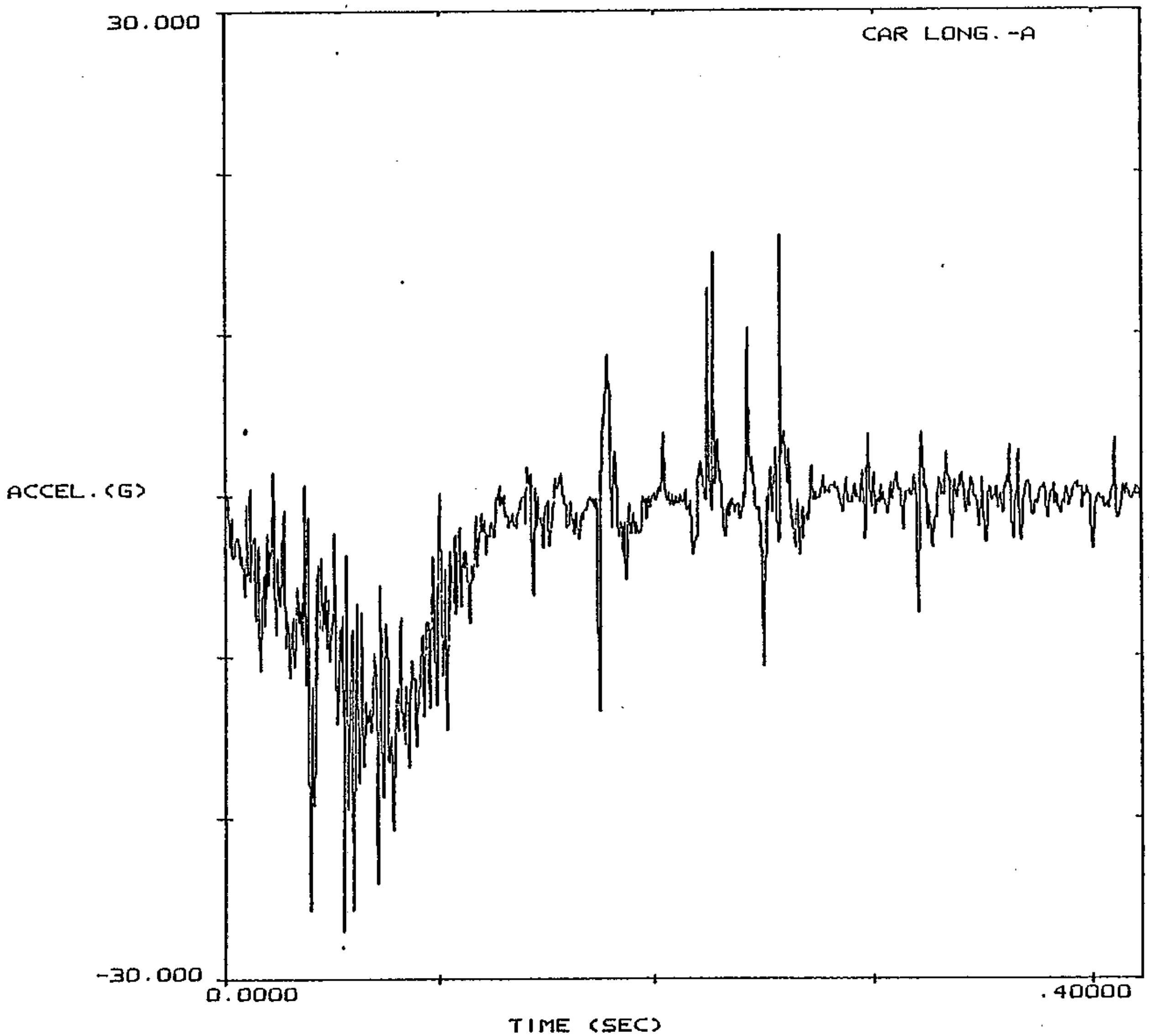


FIGURE C7 - Vehicle Longitudinal Acceleration vs Time.

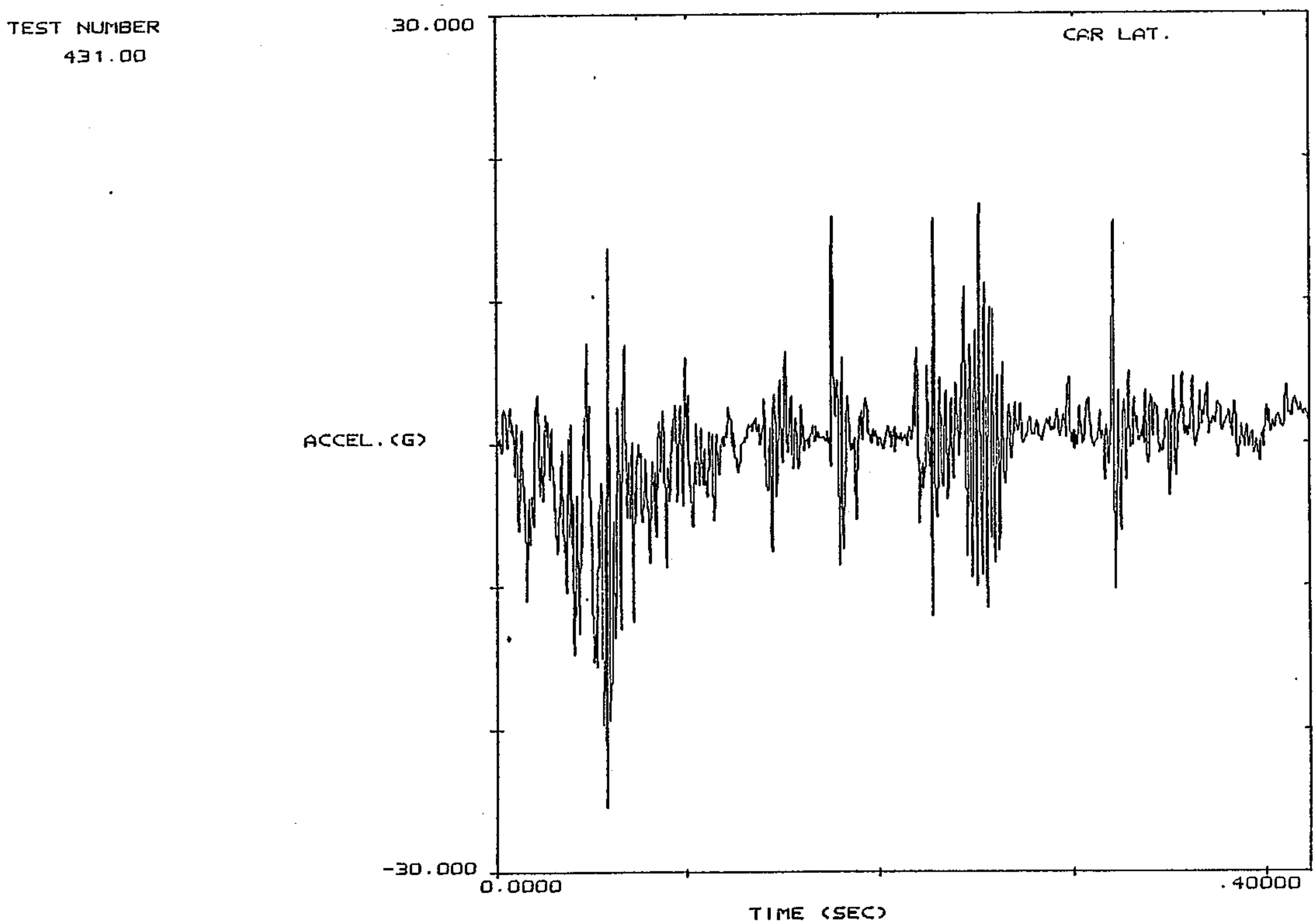
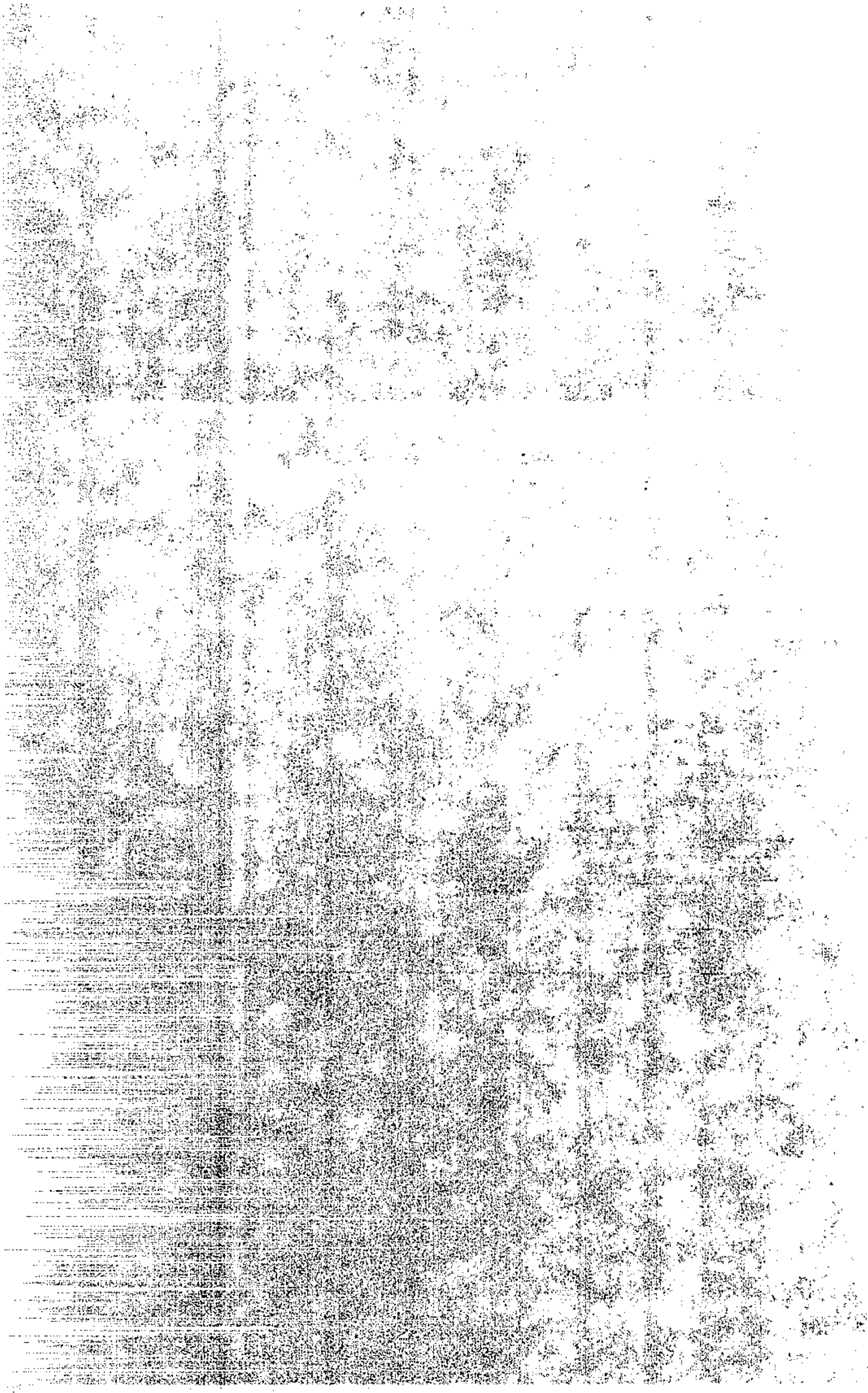


FIGURE C8 - Vehicle Lateral Acceleration vs Time.



TEST NUMBER
431.00
CQNC.
MEDIAN
BARRIER

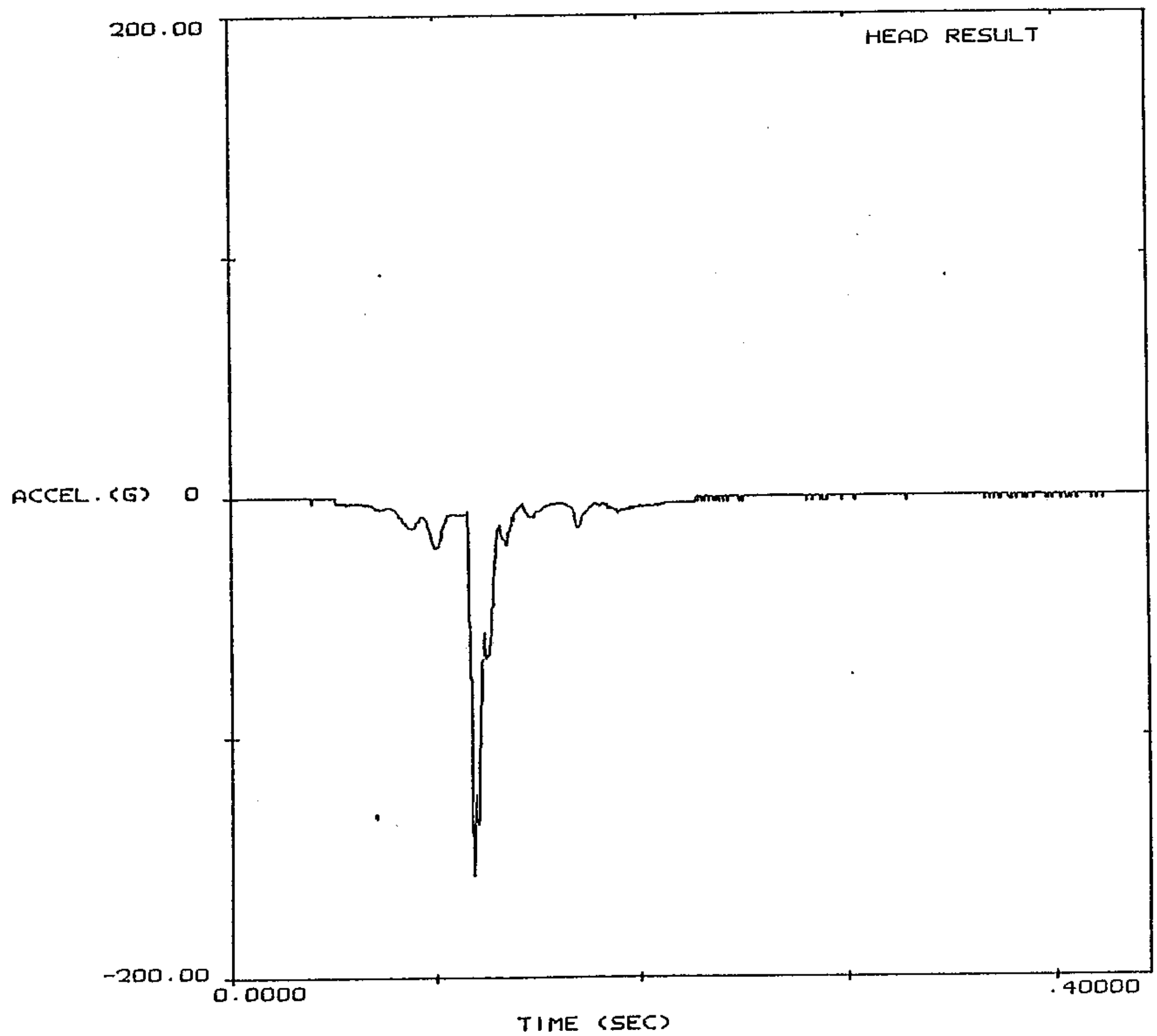


FIGURE C9 - Dummy Head Resultant Acceleration vs Time.

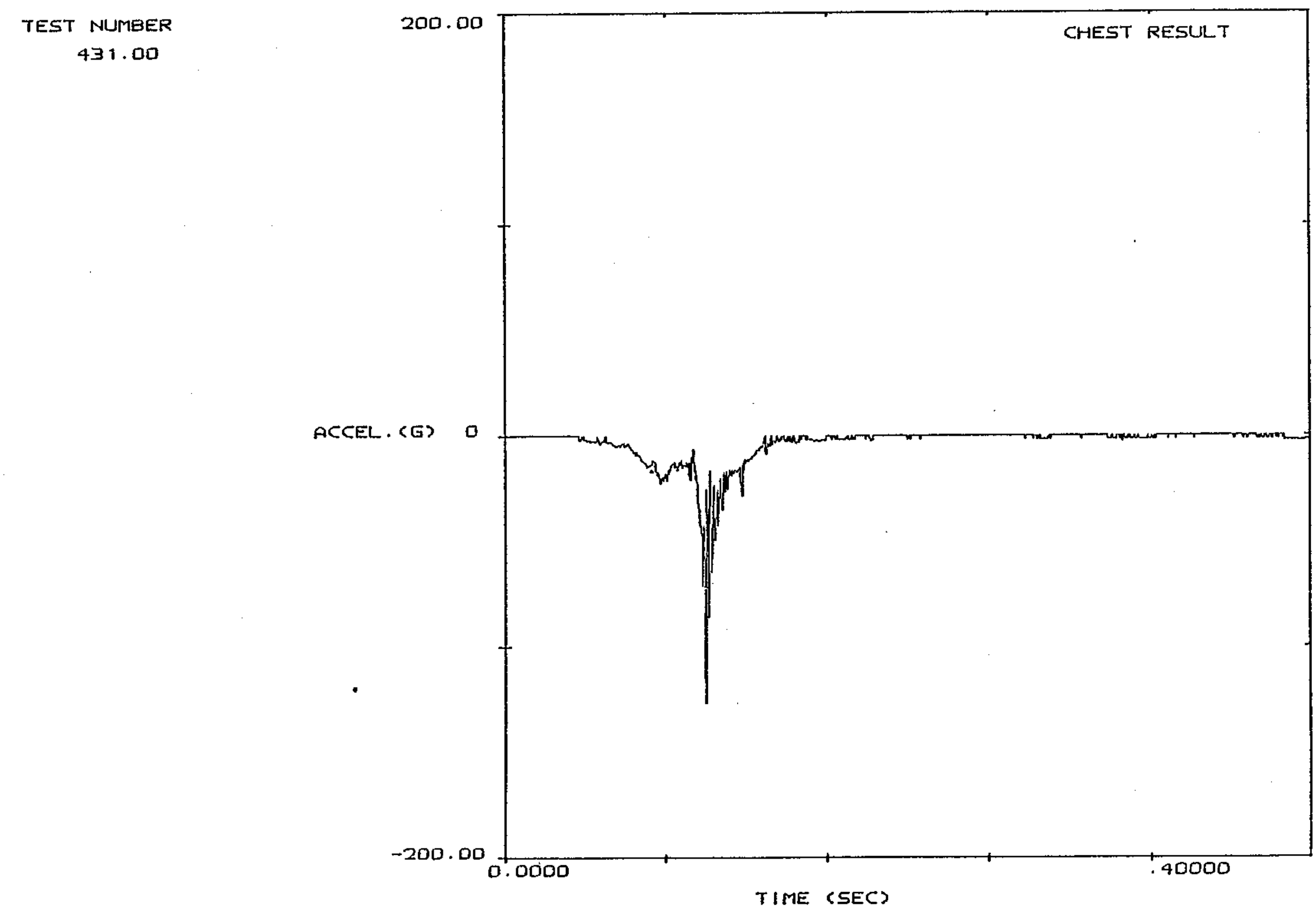


FIGURE C10 - Dummy Chest Resultant Acceleration vs Time.

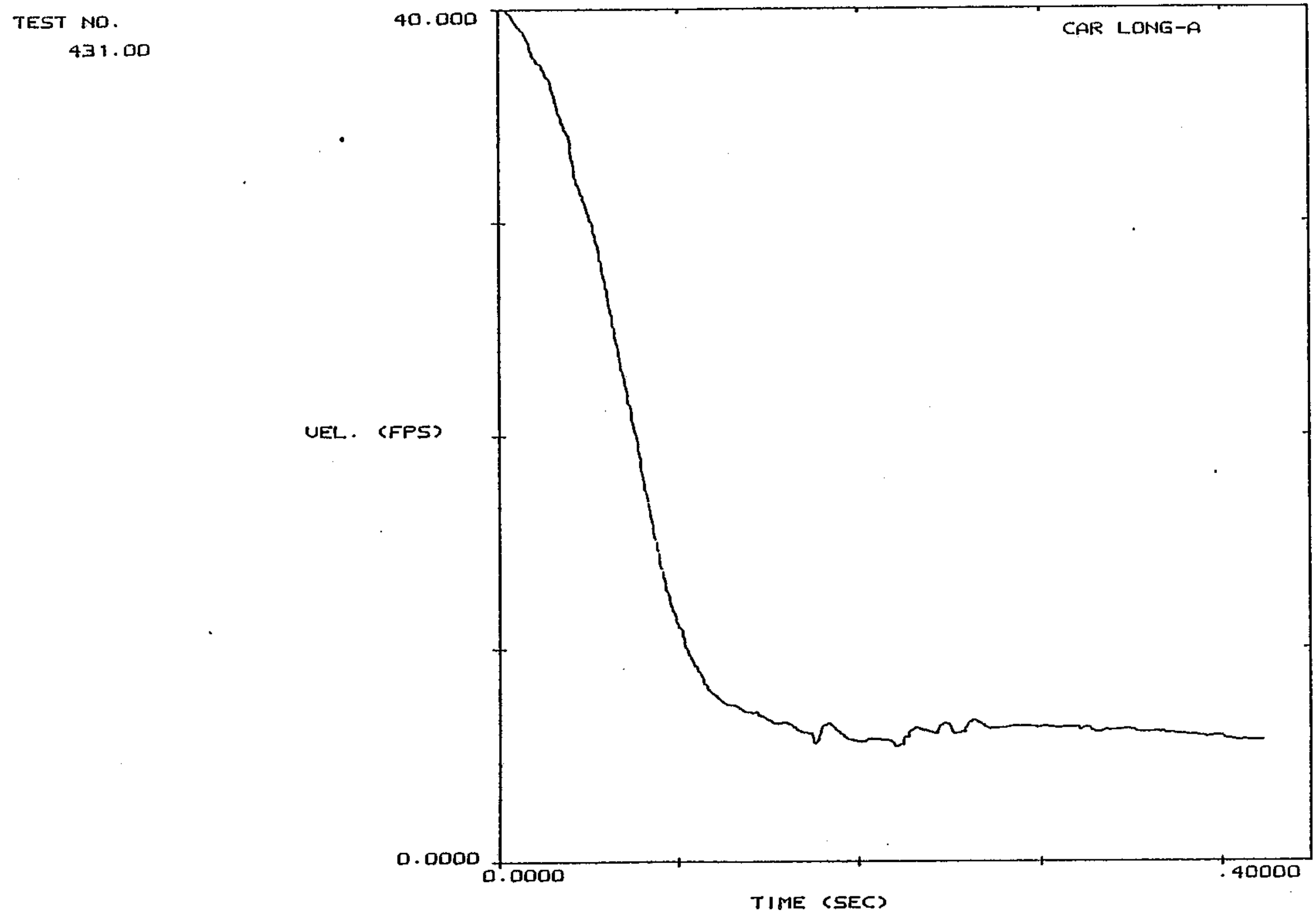


FIGURE C11 - Vehicle Longitudinal Velocity vs Time.

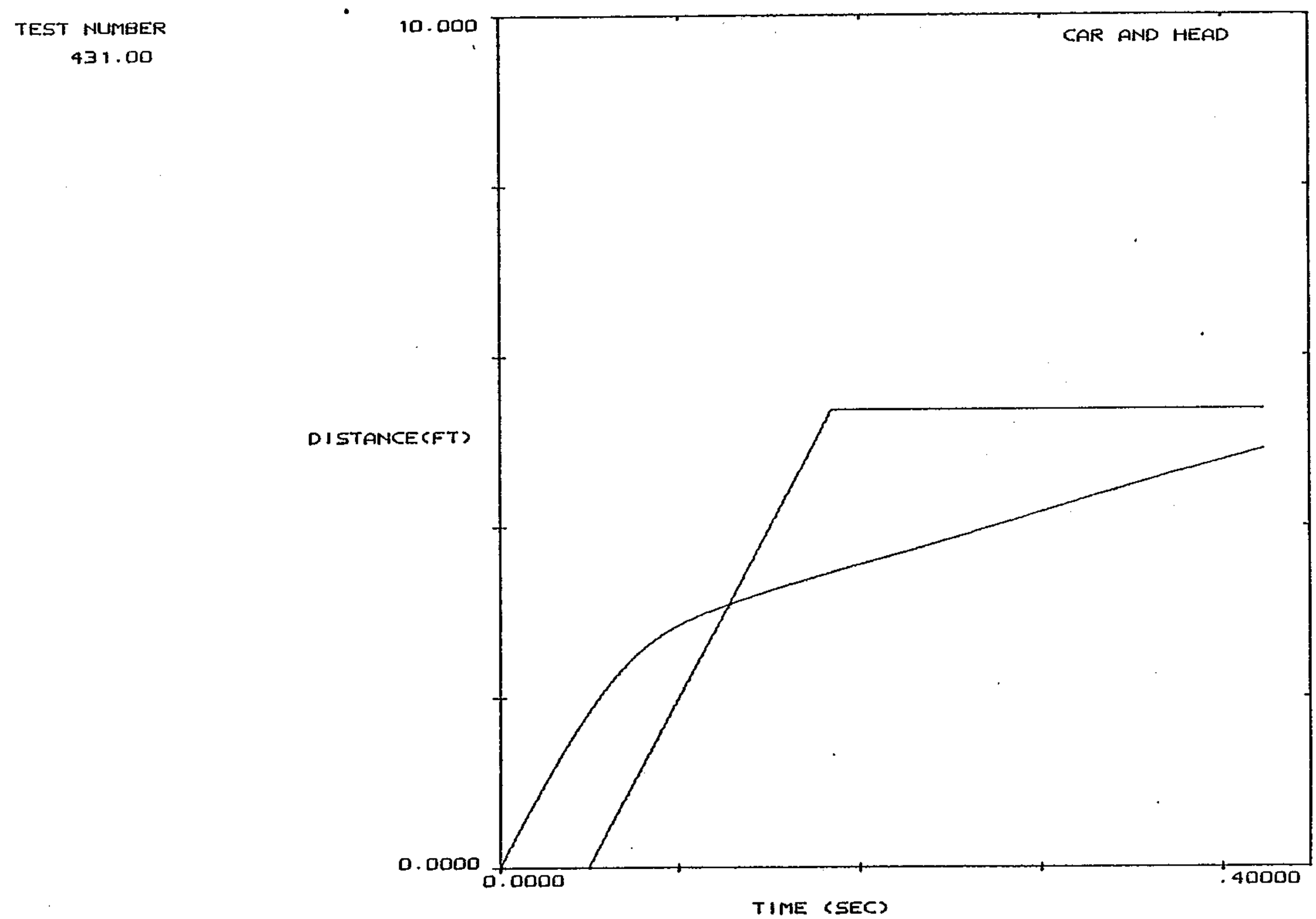


FIGURE C12 - Dummy (Theoretical) and Vehicle Longitudinal Distance vs Time Used to Find Occupant Impact Velocity.

Distance vs Time and the plots used to determine Occupant Impact Velocity. Figures C11 and C12 show blown up plots of Vehicle Longitudinal Velocity and Distance vs Time.

The occupant impact velocity is theoretical; however, on the plot of Distance vs Time Figure C4, the curves can be visualized as representing the car windshield and the driver's head. It is assumed that the head starts out two feet behind the windshield. The point where the distance curves cross represents the impact between the head and the windshield, because the windshield has slowed down from the impact velocity and the head has not. The time when the windshield/head impact occurs (rattlespace time) is carried to the plot of velocity vs time. The occupant impact velocity is the difference between the vehicle impact velocity and the vehicle velocity at the end of the rattlespace time.

(The dummy accelerometers are not used in determining the occupant impact velocity, only the vehicle accelerometers.)